

CHAPTER V

DESIGN OF WATER TREATMENT PROCESSES

A. INTRODUCTION

This chapter describes considerations involved in the design of water treatment processes. Through appropriate selection of individual processes and treatment sequences to suit the nature and quality of the raw water supply, and with good operating practices, it is possible to produce a finished water for consumers which will comply fully with KDHE criteria for biological, chemical, physical and radiological quality.

KDHE criteria consist of MCLs for primary and secondary contaminants. Primary MCLs are mandatory and secondary are not. Where treatment techniques are substituted for MCLs because routine monitoring is not economically or technologically feasible, there are recommended BAT processes or comparable substitutes which can be used. Under KAR 28-15-20, variances may be authorized by KDHE for PWSSs that cannot comply with a MCL or to those PWSSs that have installed BAT treatment for the MCL being violated. Also under this regulation, exemptions may be authorized by KDHE to a PWSS from a MCL or a treatment technique requirement. The primary difference between an exemption and a variance is that treatment does not have to be installed before the PWSS applies for an exemption.

The existing KDHE criteria are based on federal regulations promulgated for the 83 contaminants which must be regulated by EPA. KDHE will continually revise its criteria as new regulations are promulgated. PWSSs must stay abreast with these changes by anticipating their impact on existing treatment facilities and their ability to meet the MCL, and to plan upgrading of the facilities where necessary. This difficult task should consider alternate water resources and phased construction of process trains so that additions or changes can be made with minimal interruption to the treatment system and minimal cost to the PWSS.

B. SUMMARY OF REGULATORY TREATMENT REQUIREMENTS

1. SCOPE OF REVIEW - The design engineer has many treatment options to choose from, but as a minimum, they must include those required by Kansas law. KDHE required water treatment methods are reviewed according to:
 - a. The type of system they must serve.
 - b. Whether they are MCL or treatment technique controlled. What BAT processes are required and what substitutes exist for BAT processes (including identification of pertinent design sections).

- c. Whether variances or exemptions exist.
- d. What the current regulations are.

2. VOC REMOVAL

- a. Community and non-transient non-community PWSS are required to remove VOCs if an MCL is exceeded.
- b. BAT for all VOCs except vinyl chloride is packed-tower stripping or GAC adsorption. Packed-tower stripping is the only BAT for vinyl chloride. Pertinent design sections include:
 - 1) Aeration and Air Stripping - Section P
 - 2) Adsorption with GAC - Section Q
 - 3) Chemical Storage, Handling, and Application - Chapter IX
- c. A PWSS may apply for a variance or exemption from any VOC MCL requirement if the appropriate criteria are met (see KAR 28-15-20).
- d. KAR 28-15-13 includes the VOC MCLs.

3. FLUORIDE CONTROL

- a. All PWSSs must meet the MCL for fluoride and KDHE will approve the fluoridation of a PWSS within the limits of the SMCL when specific conditions are met.
- b. Central treatment using activated alumina adsorption or reverse osmosis is specified as BAT for fluoride removal. Pertinent design sections include:
 - 1) Removal of Trace Inorganic Contaminants - Section R
 - 2) Fluoridation - Section T
 - 3) Chemical Storage, Handling, and Application - Chapter IX
- c. A PWSS may apply for a variance or exemption from the fluoride MCL.
- d. KAR 28-15-13 includes the fluoride MCL and SMCL.

4. CLARIFICATION AND DISINFECTION OR MICROBIAL REMOVAL AND INACTIVATION - for *Giardia*, *Legionella*, HPC bacteria, total coliforms (including fecal coliform and *E. coli*), viruses, and turbidity.
- a. Disinfection is required for all PWSSs. All PWSSs that use surface water or GWUI must provide microbial removal and inactivation which includes clarification and disinfection. Clarification may be by conventional filtration which usually means rapid mix, coagulation, flocculation, sedimentation, and filtration with protected storage. Other non-conventional treatment options include the use of solids contact and direct filtration, microfiltration, and reverse osmosis. Softening when used separately or in combination with clarification will accomplish microbial removal and inactivation.
 - b. Treatment technique requirements are used in place of MCLs for all surface water or GWUI PWSSs. Treatment must achieve three-log removal and/or inactivation of *Giardia* and four-log removal and/or inactivation of viruses. Turbidity limits are established for PWSSs that currently have filtration. Also, residual disinfectant levels must be maintained in the distribution system for all PWSSs. Total coliform control is confirmed by monitoring requirements identified in a written sample siting plan. Finally, predetermined CT values must be satisfied for the operating treatment scheme. Pertinent design sections include:
 - 1) Clarification or Conventional Filtration, Section E to J
 - 2) Softening or Hardness Removal - Section K
 - 3) Disinfection - Section M
 - 4) Membrane Separation Processes - Section S
 - 5) Chemical Storage, Handling, and Application - Chapter IX

- c. No variances from the total coliform, filtration, and disinfection requirements are allowed for surface water or GWUI PWSSs. Exemptions are allowed for all requirements except total coliforms and disinfection residual requirements at the point of entry to the distribution system.
- d. KAR 28-15-21 includes the requirements for treatment techniques, and KAR 28-15-13 and 28-15-14 include monitoring requirements for turbidity and total coliforms.

5. CORROSION CONTROL FOR LEAD AND COPPER.

- a. Community and non-transient, non-community PWSSs are required to meet the lead and copper rule. All PWSSs serving more than 50,000 customers are required to conduct corrosion control studies unless they can demonstrate to KDHE that corrosion control has been optimized. For smaller PWSSs, the requirement for corrosion control studies will be triggered by lead and copper action levels.
- b. Treatment technique requirements are triggered when action levels for lead and copper are exceeded and they consist of optimal corrosion control, source water treatment, public education, and lead service line replacement for lines under the direct control of the PWSS. Treatment of source water may include conventional filtration, lime softening, ion exchange, reverse osmosis, or alternate treatment methods at least as effective as these. Pertinent design sections include:
 - 1) Clarification or Conventional Treatment - Sections E to J
 - 2) Softening or Hardness Removal - Section K
 - 3) Membrane Separation Processes - Section S
 - 4) New Processes, Methods, Chemicals, and Equipment - Chapter III, Subsection 18.
 - 5) Chemical Storage, Handling, and Application - Chapter IX
- c. KAR 28-15-13 contains the action levels for lead and copper.

6. IOC and SOC REMOVALS

- a. Community and non-transient, non-community PWSSs are required to meet the MCLs for IOCs and SOCs.
- b. 40 CFR §141.61 and §141.62 list the BAT treatment processes required for all inorganic and synthetic organic chemicals except acrylamide and epichlorohydrin for which specific dosage limitations are specified in 40 CFR §141.111. KDHE may require the use of POU, bottled water, or other means to reduce contaminants to acceptable levels. Pertinent design sections include:
 - 1) Clarification or Conventional Treatment - Section E to J
 - 2) Softening or Hardness Removal - Section K
 - 3) Aeration and Air Stripping - Section P
 - 4) Adsorption with GAC - Section Q
 - 5) Removal of Trace Inorganic Contaminants - Section R
 - 6) Membrane Separation Processes - Section S
 - 7) New Processes, Methods, Chemicals, and Equipment - Chapter III, Subsection A.5.
 - 8) Chemical Storage, Handling, and Application - Chapter IX
- c. KDHE may issue a variance if it determines that a system cannot comply with an MCL despite application of BAT. Also, an exemption may be issued if the appropriate criteria are met.
- d. KAR 28-15-13 contains MCLs for the regulated IOCs and SOCs.

7. RADIONUCLIDE REMOVAL

- a. Community and non-transient, non-community PWSSs are required to meet the MCLs for radionuclides.

- b. BAT is required for all regulated radionuclides in excess of the MCLs. Treatment processes for radium 226 and 228 include softening, ion exchange, reverse osmosis, and electrodialysis. Radon can be removed by aeration. Treatment processes for uranium are conventional filtration, softening, ion exchange, reverse osmosis, electrodialysis, and activated alumina adsorption. Pertinent design sections include:

- 1) Clarification or Conventional Treatment - Section E to J
- 2) Aeration and Air Stripping - Section P
- 3) Adsorption with GAC - Section Q
- 4) Removal of Trace Inorganic Contaminants - Section R
- 5) Membrane Separation Processes - Section S
- 6) New Processes, Methods, Chemicals, and Equipment - Chapter III, Subsection A.5.
- 7) Chemical Storage, Handling, and Application - Chapter IX

- c. Variances and exemptions are allowed according to KDHE criteria.

- d. KAR 28-15-13 contains MCLs for combined radium-226 and radium-228, gross alpha particle activity (including radium-226 but excluding radon and uranium), tritium, strontium-90, and gross beta radioactivity.

8. DBPs CONTROL AND REMOVAL

- a. Community and non-transient, non-community PWSSs are required to meet MCLs for DBPs.

- b. DBPs can be controlled by the removal of precursors, selecting alternate disinfectants, and/or the removal of by-products. Processes for the control of precursors at the source are selective withdrawal from reservoirs, plankton control, and alternative water resources. In-plant control methods include moving the point of

chlorination, selective use of oxidizing agents to control DBP formation potential, use of chloramines, and pH adjustment to reduce the reactions producing DBPs.

Treatment processes for the removal of precursors include clarification, softening, GAC adsorption, and chemical oxidation. Alternate disinfectants include chlorine dioxide and ozone. Removal of some by-products can be accomplished using air stripping, GAC adsorption, and reducing or oxidizing agents. Pertinent design sections include:

- 1) Clarification or Conventional Treatment - Sections E to J
- 2) Softening or Hardness Removal - Section K
- 3) Disinfection - Section M
- 4) T&O Control - Section N
- 5) Aeration and Air Stripping - Section P
- 6) Adsorption with GAC - Section Q
- 7) Chemical Storage, Handling, and Application - Chapter IX

- c. Variances and exemptions are allowed according to KDHE criteria.

C. SUMMARY OF OPTIONAL TREATMENT REQUIREMENTS

1. INTRODUCTION - Several optional, conventional treatment processes are used depending upon the particular needs of a PWSS. These processes are optional in that no statutory requirement exists for their use. SMCL contaminants are typically removed in these processes. A format similar to the preceding section is used to summarize the basic treatment requirements of:

- a. The communities affected.
- b. The existing SMCL or the alternate treatment techniques used (including the identification of pertinent design sections).
- c. The regulations impacting the process choice.

2. SOFTENING OR HARDNESS REMOVAL

- a. Softening is desirable for PWSSs where excessive hardness is present and where reduction of the calcium and magnesium will reduce the total dissolved solids.
- b. Softening may be accomplished by addition of lime alone where natural alkalinity will permit, or by addition of lime and soda ash where removal of non-carbonate hardness is required. Also, softening may be accomplished by the use of sodium zeolite and other ion removing resins regenerated by strong acids, strong bases or other regenerants, depending on the quality of raw water available and the quality of treated water desired. Pertinent design sections include:
 - 1) Softening or Hardness Removal - Section K
 - 2) Removal of Trace Inorganic Contaminants - Section R
 - 3) Membrane Separation Processes - Section S
 - 4) Chemical Storage, Handling, and Application - Chapter IV
- c. Softening is defined as calcium and magnesium removal but it also results in the removal of other contaminants, some of which are regulated and some of which are not. Fluorides, microbes, heavy metals (e.g., lead and copper), organics and other inorganics, and radionuclides are examples of regulated contaminants affected by softening. Besides calcium and magnesium, SMCL contaminants affected by softening include total dissolved solids, zinc, aluminum, silver, and pH.

3. IRON AND MANGANESE REMOVAL

- a. Removal of iron and manganese is desirable for a PWSS when natural waters containing iron in excess of 0.3 mg/L or manganese in excess of 0.05 mg/L.
- b. Treatment processes include conventional treatment, softening, ion exchange, aeration, reverse osmosis, electrodialysis, and chemical oxidation. Pertinent design sections include:
 - 1) Clarification or Conventional Treatment - Section E to J

- 2) Softening or Hardness Removal - Section K
 - 3) Iron and Manganese Removal - Section O
 - 4) Aeration and Air Stripping - Section P
 - 5) Membrane Separation Processes - Section S
 - 6) New Processes, Methods, Chemicals, and Equipment - Chapter III, Subsection A.5.
 - 7) Chemical Storage, Handling, and Application - Chapter IX
- c. Iron and magnesium are SMCL contaminants and are removed in a variety of treatment processes. Also, as in the case of hardness removal, other contaminants are removed along with iron and magnesium depending upon the type of process used.

4. HYDROGEN SULFIDE REMOVAL

- a. Removal of hydrogen sulfide is desirable for a PWSS when its odor is present in the finished water.
- b. Treatment processes include aeration and chemical oxidation. Pertinent design sections include:
 - 1) Clarification or Conventional Treatment - Section E to J
 - 2) T&O Control - Section N
 - 3) Aeration and Air Stripping - Section P
 - 4) Chemical Storage, Handling, and Application - Chapter IX
- c. Hydrogen sulfide is removed by air stripping or volatilization in the aeration process as are VOCs and carbon dioxide. Chemical oxidation changes the chemistry of the sulfur resulting in its control. Many IOCs and SOCs can be affected by chemical oxidation.

D. GENERAL DESIGN CONSIDERATIONS

1. GENERAL CRITERIA - Certain features should be included in the design of treatment processes regardless of whether they are required or optional. The following considerations should be reviewed for each process design and for the combined treatment train:
 - a. REQUIRED PROCESS EFFICIENCY - MCL based processes must achieve a certain level of efficiency under the most critical process constraints. Not all contaminants have designated MCLs, i.e., they are to be removed based on designated treatment techniques, in which case the degree of removal will be determined by the BAT.
 - b. MINIMUM NUMBER OF UNITS - There should usually be at least two units of the same process so that one can be used in the event that the other is inoperable.
 - c. PIPING - Both series and parallel flow should be provided between units to maximize treatment options. A bypass should be provided to enable a unit to be removed from service.
 - d. FLOW REGIME - Internal and external flow control devices and the unit itself should provide the desired flow regime of plug flow, complete mixing, or intermediate regimes.
 - e. CHEMICAL ADDITION - Many treatment units require facilities for the addition of chemicals to facilitate the process needs.
 - f. HYDRAULIC - Head losses should be minimized to reduce costs but not to the point of affecting the desired flow regime or flow control.
 - g. PROCESS CONTROL - Automatic control of a process is desirable, especially where operator error is probable or an operator's attention is limited. Manual operation must always be possible where automatic controls are used.
 - h. MONITORING - Process control and/or regulatory requirements involve the use of monitoring facilities to determine various quantity and quality parameters. Provision should be made to take samples and measure process variables.

- i. CLIMATE AND WEATHER - Many treatment units will be affected by seasonal and temporal variations of meteorological conditions.
 - j. SAFETY - Operator and customer safety are absolute requirements for process design.
 - k. ADJUSTABLE FEATURES AND FUTURE NEEDS - The possibility of process modifications, expansions or other changes to the unit must be considered. These may be minor changes or adjustable features (such as alternate chemical feeding locations, adjustable mixing energy input, adjustable weirs, addition of baffles, and provision for monitoring) which could have a significant impact on treatment efficiency with their incremental costs or major ones resulting in large capital expenditures.
- 2. PERMIT APPLICATION - A permit application and plans are required for alterations or improvements involving a change in the treatment methods or the design capacity (see Chapter II).
 - 3. REMAINING CHAPTER ORGANIZATION - The remaining sections in Chapter V review the design criteria for the various treatment processes used to accomplish contaminant removal or control. The sequence of processes do not follow any particular order except that those listed first are common to surface water treatment plants. Each plant will have its own unique sequence of processes depending upon site specific conditions and the preferences of the design engineer.
- E. PRESEDIMENTATION** - Surface waters or GWUI which have gravel, sand, silt, or turbidity in excess of 1,000 NTUs should have pretreatment. Presedimentation, either with or without the addition of coagulation chemicals, is recommended.
- 1. BASIN DESIGN - Sedimentation basins should have hopper bottoms or be equipped with continuous mechanical sludge removal devices especially selected or designed to remove gravel, sand and/or heavy silt. They should include provisions for rapid draining and hydraulic flushing.

2. CHEMICAL ADDITIONS - Provision should be made for adding chlorine and other chemicals for taste and odor control, color removal, and improved removal of turbidity. Also, removal of suspended solids by presedimentation should be enhanced by adding chemical coagulants and rapid mixing. Acrylamide and epichlorohydrin are impurities found in organic polymers used as coagulant aids. Each PWSS must certify annually that the chemicals it uses do not exceed EPA specified levels based upon dosage and percentage of the compound in the coagulant aid (see 40 CFR §141.111).

3. PRESEDIMENTATION CRITERIA

- a. DETENTION TIME - The minimum detention period recommended is 45 min except for the Kansas and Missouri River sources which are 2 and 3 hours, respectively.
- b. OVERFLOW RATE - The maximum recommended surface overflow rate is 3,500 gpd/ft² (143,000 Lpd/m²).
- c. WATER DEPTH - The minimum recommended depth is 8 ft (2.5 m).
- d. WEIR RATE - The maximum recommended weir rate is 20,000 gpd/ft (248,386 Lpd/m).
- e. DRAIN LINES - The minimum recommended diameter for drain lines is 8 in (200 mm).
- f. BYPASS - Piping and controls for bypassing presedimentation basins shall be provided.

F. RAPID MIXING AND COAGULATION - Rapid mixing is violent agitation to rapidly disperse coagulation chemical(s) and/or recycled softening solids throughout the water being treated. Coagulation is the process of neutralizing the charges on suspended particles and colloids. The design engineer shall identify the basis for rapid mix and coagulation in terms of the detention time and G values or other appropriate measure of mixing effectiveness for the expected water quantity and quality variations and the chemical(s) to be added. At least the following items should be evaluated when designing a rapid mix system: type of coagulant to be employed, number of chemicals to be fed and the characteristics of each, raw water characteristics, type of chemical diffusers, available headloss for the flash mixer, variations in the plant flow rate, and type of subsequent process.

1. REQUIREMENT - Any of several types of mixers can be used to accomplish rapid mixing. These include mechanical, diffusers and injectors, hydraulic, in-line blenders (mechanical and static) and pumps. Baffled mixing chambers are not allowed when they serve as the only means of mixing.
2. LOCATION - The rapid mix and flocculation basins shall be as close together as possible to minimize incidental flocculation which can result in fragmented floc and process inefficiencies. Typical velocities in conduits from the mixer to flocculation basins are 1.5 to 3.0 ft/s (0.45 to 0.9 m/s). Distribution channels between the two units are often tapered, either in width or depth, so as to maintain a constant velocity.
3. RAPID MIX CRITERIA - Inorganic coagulants destabilize colloids by adsorption and charge neutralization or by sweep coagulation. Polymers use charge neutralization and interparticle bridging mechanisms. The mechanism of colloid destabilization will dictate the chemical dose and the rapid mix design criteria that should be used. Although the velocity gradient (G value) has been widely used as the primary design criteria for evaluating rapid mixers, recent studies have suggested alternate design parameters such as the total power input to the water per unit flow rate (e.g. hp/mgd or hp/cfs). Further, for the in-line or pump-injected rapid mixing devices, G is difficult to calculate because the volume to be used in the calculation of G is uncertain. Design criteria utilized for a specific rapid mix system should be clearly identified by the design engineer.
4. MECHANICAL MIXERS - ALUM COAGULATION WITHOUT SOFTENING SOLIDS RECYCLE
 - 1) DETENTION TIME - For conventional treatment plants, the required mixing time should not exceed 30 sec at the maximum flow rate and should in most cases be less than 10 sec. Alum coagulation with adsorption and charge neutralization may be most efficient at detention times less than 0.1 sec while sweep coagulation with alum requires 1 to 7 sec.

- 2) **G VALUES** - For alum mixing, the recommended minimum G value is 500 sec⁻¹. For alum and polymer mixing, the recommended G value is in the range of 600 to 1000 sec⁻¹.
- 3) **CALCULATION OF G** - The velocity gradient G may be calculated from the following equation:

$$G = \sqrt{\frac{550P}{\mu V}}$$

where,

G = velocity gradient, second s⁻¹
 P = applied horsepower, hp
 V = effective volume, ft³
 μ = viscosity, lb·s/ft²

The equation in SI units is

$$G = \sqrt{\frac{kW \times 10}{\mu V}}$$

where,

G = velocity gradient/second s⁻¹
 kW = applied energy, kW
 V = volume, m³
 μ = viscosity, cP

5. **pH CRITERIA** - The optimum pH for coagulation varies. The pH range for alum is 5.5 to 7.5, typically 7.0; for ferric salts, the range is 5.0 to 8.5, typically 7.5. Actual values for the proposed design can be determined by experimentation. Chemicals used to adjust the pH should be added before the coagulant chemicals although they can be added together.
6. **SOFTENING REQUIREMENTS** - When coagulation and softening are to occur simultaneously in a process sequence of rapid mixing, flocculation and sedimentation or together in a single solids contact unit, it is important to determine the correct order of chemical additions.

G. **FLOCCULATION** - Flocculation is the agitation of water at low Gs for extended time periods to facilitate the aggregation of smaller particles into larger particles suitable for settling by gravity. It is a followup process to rapid mixing for coagulation and/or softening.

1. REQUIREMENT - A mechanical unit is required in conjunction with the rapid mix unit in all new treatment plants and where existing plants are upgraded.
2. EXCEPTION - A separate mechanical unit will not be required where a solids contact basin with a reaction/mixing compartment is provided.
3. BASIN DESIGN
 - a. Inlet and outlets should be designed to minimize floc destruction and short circuiting.
 - b. Provision for decreasing mixing energies is required where up to three compartments in series are used. Series compartments in a single basin are recommended in preference to separate basins in series.
 - c. Drains or pumps shall be provided to handle dewatering and sludge removal.
 - d. Pilot or in-plant studies should confirm the value of recycling floc, softening solids, or filter wash water into the mixing and flocculation stage to improve their efficiency and reduce chemical requirements. Equalization must be provided to avoid disrupting the coagulation and flocculation processes since a constant recycle works best.

Recycle of filter wash water for water conservation is usually done using a recovery tank where the supernatant is recycled and the solids are handled separately. The recycle of filter wash water is not recommended where there is the potential of an accumulation of toxic materials or organisms in the recycled water.

4. DETENTION TIME - A minimum of 30 min is required at the maximum design flow to allow for good floc formation. Increased time is required where a series of separate flocculation basins are used. Detention times should be adjusted for temperature effects according to the guidelines in Table 3.

TABLE 3

TEMPERATURE ADJUSTMENT GUIDELINES
FOR FLOCCULATOR DETENTION TIME (7)

Temperature, °C	Detention Time Factor
0	1.35
5	1.25
10	1.15
15	1.07
20	1.00
25	0.95
30	0.90

5. EQUIPMENT

- a. Agitators are to be driven by variable speed drives. For vertical, low energy and horizontal, paddle-type flocculators, blade tip speeds in the range of 0.5 to 3.0 ft/sec (0.15 to 0.92 m/s) are appropriate for maximum floc growth and settleability. The maximum tip speed for vertical, high energy flocculators should not exceed 10 ft/sec (3 m/s).
- b. Where three basins in series are used, Gs from 40 to 60 sec⁻¹ in the first cell down to 15 to 25 sec⁻¹ in the last cell are suggested. Higher values are used for softening when used alone or in combination with clarification to prevent solids deposition. Vertical, high energy flocculators have Gs of 50 to 75 sec⁻¹ compared to 20 to 45 sec⁻¹ for vertical, low energy and horizontal paddle-type flocculators.
- c. External, non-submerged drive equipment is recommended.

- d. A superstructure over the flocculation basins may be appropriate.

6. PIPING

- a. The flocculation and sedimentation basins shall be located as close together as feasible.
- b. The velocity of the flocculated water through pipes, flumes, or effluent ports leading to the settling basin should not exceed 1.5 ft/sec (0.46 m/s) to avoid floc shear and should not be less than 0.5 ft/sec (0.15 m/s) to prevent settling before entering the basin. Most flocculators have an end baffle between the flocculation zone and the clarifier to prevent residual energy of the flocculation process from being transferred to the clarification stage.
- c. Allowances must also be made to minimize turbulence at bends and changes in direction.

H. **SEDIMENTATION** - Sedimentation shall follow flocculation except where dissolved air flotation or direct filtration has been approved (see Section I on Dissolved Air Flotation or Section J on Filtration).

- 1. GENERAL REQUIREMENTS - The requirements for effective clarification are dependent upon a number of factors related to basin design and the nature of the raw water (turbidity, color, colloidal matter, taste and odor causing substances, or other material to be removed). The character of the floc formed is a major consideration. Sound engineering judgment is required to produce a good cost-effective design.
 - a. **BASIN DESIGN** - The basins may be designed for conventional or solids contact units. Conventional units can be circular, square, or rectangular; however, square basins will be approved only under special conditions. Solids contact basins are upflow units that utilize a zone where previously formed and settling floc interacts with incoming particles.
 - b. **INCLINED SETTLERS** - Approval has been given for the use of plate or tube settlers and a reduction in detention time is allowed with their use.

- c. DETENTION TIME - Calculations for detention time requirements should be based on the maximum design flow.
- d. INLETS - Inlets for square or rectangular horizontal flow units should be designed to distribute the flow uniformly across the cross section of the basin at a constant velocity. Open ports, submerged ports, and similar entrance arrangements are recommended. A baffle should be constructed across the basin close to the inlet end. It should dissipate inlet velocities and provide uniform flow across the basin. Baffle walls are more effective than target baffles. Circular basins may have a center feed with radial flow, or peripheral or rim-feed with radial flow. Regardless of the type of flow regime, the design should provide a proper flow pattern with minimal floc breakup.
- e. OUTLET AND OVERFLOW DEVICES - Means for controlling the maximum water level in the filters and basins shall be provided. Outlets, when used, should be designed to maintain velocities suitable for settling in the basin and to minimize short circuiting. Weirs or submerged orifices can be used to facilitate clarified water removal and minimize short circuiting. An overflow weir can be installed which will establish the maximum water level desired on top of the filters and will discharge by gravity with a free fall at a location where the discharge will be seen.

Weirs should be easily accessible for cleaning and maintenance. Each trough section should have sufficient drain holes in the bottom to relieve loadings when the basin is drained and prevent buoyancy uplift during basin filling. When excess lime softening is practiced, overflow weirs and troughs will tend to encrust with precipitated CaCO_3 . A submerged weir takeoff minimizes this problem.
- f. DRAINAGE - Basins should be provided with a means for dewatering. Basin bottoms should slope toward the drain. Drainage facilities shall not be connected to the sanitary sewer system except where proper cross-connection protection is provided such as an air-gap separation between the basin and the sanitary sewer connection.

- g. SLUDGE COLLECTION - Mechanical sludge collection equipment shall be provided.
- h. SLUDGE REMOVAL - Sludge removal design shall provide that:
 - 1) Sludge pipes shall be not less than 8 in (20 cm) in diameter and so arranged as to facilitate cleaning.
 - 2) Entrance to sludge withdrawal piping shall prevent clogging.
 - 3) Valves shall be located outside the tank for accessibility.
 - 4) The operator can observe and sample sludge being withdrawn from the unit.
- i. SLUDGE DISPOSAL - Facilities are required for disposal of sludge.

2. CONVENTIONAL BASIN CRITERIA

a. MINIMUM DETENTION TIMES

- 1) When no inclined settlers are used:
 - a) Kansas, Missouri, and Neosho Rivers:
 - (1) With presedimentation - 3.0 hr.
 - (2) Without presedimentation - 4.0 hr.
 - b) All other surface supplies - 3.0 hr.
 - c) Lime-soda ash softening facilities treating groundwater - 2.0 hr.
- 2) When inclined settlers are used:
 - a) Missouri and Kansas Rivers - designer must justify reduced detention times.
 - b) Neosho River - 2.0 hr.
 - c) Others - 1.5 hr.

b. OVERFLOW RATE

- 1) The recommended maximum surface overflow rate for horizontal flow basins is 600 gpd/ft² (14,000 Lpd/m²).

- 2) When effluent weirs are used in lieu of a ported outlet wall, the rate of flow over the outlet weir should not exceed 20,000 gpd/ft (248,000 Lpd/m) of weir length for horizontal flow basins. The extent of weir-trough distribution should not exceed 1,440 to 2,160 gpd/ft² (58,700 to 88,000 Lpd/m²) rise rate for the surface area covered by the trough system. Their coverage should extend one-third to preferably one-half of the basin length toward the inlet end. Circular basins greater than 50 to 60 ft (15.2 to 18.3 m) in diameter are improved by the use of an inboard circumferential weir. A double-sided weir trough mounted inboard at least 15 percent of the tank radius is recommended.
 - 3) Submerged exit ports used as an alternative for overflow weirs should be located no more than 3.0 ft (0.91 m) below the water line at maximum flow with loading rates equivalent to the weir loading rate in part b., 2) above.
- c. BASIN DIMENSIONS - Circular center feed clarifiers less than 125 ft (38.1 m) in diameter perform as well as long rectangular tanks. Larger diameter basins require provisions to insure that uniform radial flow is produced by the inlet device.
- 1) Minimum depth - 8 ft (2.5 m).
 - 2) Minimum recommended length to width ratio of rectangular settling basins is 2.5:1. Ratios of 4:1 or more are recommended.
- d. INCLINED SETTLERS - Where existing basins are adequate structurally and hydraulically, the capacities may be doubled by installing approved inclined settlers (tubes or plates) provided that the new detention time is not less than the standards listed above and the following criteria are met:
- 1) Application Rate - A maximum rate of 2,880 gpd/ft² (67,200 Lpd/m²) for tube or plate settlers based on 2 ft (0.6 m) long 60° tubes or 39.6 in (100 cm) long 7.5° tubes. Higher rates are not permitted unless successfully shown to be appropriate through pilot plant or in-plant demonstration studies.

- 2) Protection from Freezing - Although most units will be located within a plant, outdoor installations must provide sufficient freeboard above the top of the settlers to prevent freezing in the units. A cover or enclosure is strongly recommended.
 - 3) Drainage - Drain piping from the settler units must be sized to facilitate a quickflush without flooding other portions of the plant.
 - 4) Flushing Lines - Flushing lines shall be provided to facilitate maintenance and must be protected against backflow or back siphonage.
3. SOLIDS CONTACT BASIN CRITERIA - Solids contact units are acceptable for clarification or combined clarification and softening where water characteristics are not highly variable and flow rates are uniform. Clarifiers should be designed for the maximum treatment rate.
- a. INSTALLATION AND STARTUP OF EQUIPMENT - A manufacturer's representative should supervise the installation and initial operation of all mechanical equipment.
 - b. OPERATION OF THE EQUIPMENT - The following should be provided by the manufacturer for routine plant operation of mechanical units.
 - 1) A complete set of tools and accessories.
 - 2) Identification of process control procedures and suggested test equipment.
 - 3) Sampling taps so located as to permit the collection of samples which will allow process control and monitoring requirements to be satisfied.
 - c. CHEMICAL FEED - Chemicals should be applied at such points and by such means as to insure their satisfactory mixing with the water to be treated (see Chapter IX on Chemical Storage, Handling, and Application).

d. MIXING - Mixing devices should be so constructed that:

- 1) Good mixing of the raw water with previously formed suspended particles is provided. Coagulation can occur in a separate chamber or baffled zone within the unit.
- 2) Flocculation (reaction zone in solids contact) equipment requirements are:
 - a) The mixing blade speed should generally not exceed 10 ft/sec (3 m/s) to avoid shearing the floc, but fast enough that deposition of solids in the mixing zone is prevented.
 - b) Mixers shall be adjustable for variable Gs of 20 to 70 sec^{-1} . Softening units should be capable of maintaining solids concentrations of one percent by weight.
 - c) A recirculation ratio of 10 to 1 at design flow and the top mixing speed is recommended.

e. TANK VOLUME - The volume of the mixing compartment is measured to the bottom of the skirt (compartment wall).

f. DETENTION TIME - The detention time shall be established on the basis of the raw water characteristics and other local conditions that affect the operation of the unit. Based on the maximum design flow rate, the detention time should be:

- 1) Two to four hours for solids contact clarifiers and softeners treating surface water.
- 2) One to two hours for solids contact softeners treating only groundwater.
- 3) The flocculation and mixing detention time shall be not less than 30 min nor greater than 40 min at design flow except a mixing period of not less than 15 min will be accepted for softening units.

- 4) The net detention time for the sedimentation portion of the solids contact basin is calculated from the total tank volume less the volume of the flocculation/reaction compartment. The minimum detention time for clarification shall be 3 hr. Minimum softening detention time shall be 1.5 hr.
- g. OVERFLOW RATES - Unless supporting data are submitted to KDHE to justify alternative values, the following overflow rates are required:
- 1) The overflow rate for clarification units shall not exceed 1.0 gpm/ft² (41 Lpm/m²) at the sludge separation line.
 - 2) The overflow rate for softening units shall not exceed 1.75 gpm/ft² (71 Lpm/m²) at the slurry separation line.
- h. SLUDGE REMOVAL - Equipment design should insure that:
- a) Sludge pipes are not less than 8 in (20 cm) in diameter and so arranged to facilitate cleaning.
 - b) Entrance to sludge withdrawal pipes will prevent clogging.
 - c) Valves should be located outside the tank for accessibility.
 - d) The operator can observe or sample sludge being withdrawn from the unit.
- i. SUSPENDED SLURRY CONCENTRATE - Softening units should be designed so that continuous slurry concentrates of one percent or more, by weight, can be satisfactorily maintained.
- j. WATER LOSSES
- 1) Units shall be provided with suitable controls for sludge withdrawal.
 - 2) Total water losses should not exceed:
 - a) Five percent for clarifiers.
 - b) Three percent for softeners.

k. CROSS-CONNECTIONS

- 1) Blow-off outlets and drains should terminate and discharge at places to prevent back-siphonage.
- 2) Cross-connection control should be included for the potable water lines used to backflush sludge lines.

1. OUTLETS, WEIRS, OR ORIFICES - The units should be equipped with either ported outlet walls, overflow weirs or orifices constructed so that water at the surface of the unit does not travel over 10 ft (3.0 m) horizontally to the collection trough. Required weir loadings are:

1. The weir loading for clarification units shall not be greater than 10 gpm/ft or 14,000 gpd/ft (125 Lpm/m or 180,000 Lpd/m).
2. The weir loading for softening units shall be the same as for clarification units. The weir shall be adjustable, at least equivalent in length to the perimeter of the tank if the tank is circular, and constructed so that they will produce a uniform rise rate over the entire area of the tank. When orifices are used the loading per foot of launder rates should be equivalent to the weir loadings.

I. **Flotation** - Dissolved air flotation has found limited application to the clarification of waters except for algae laden waters or where chemical coagulation produces a light, slowly settling floc such as in the treatment of low turbidity, highly colored waters. Design of DAF units must be based on pilot or in-plant demonstration studies approved by KDHE. Typical DAF units are rectangular with a depth of 5 ft (1.5 m) and a surface overflow rate in the range of 4,670 to 7,180 gpd/ft² (192,000 to 288,000 Lpd/m²). The nominal detention time in the flotation tank is between 5 and 15 min.

J. **Filtration** - The use of rapid rate gravity sand filters is recommended for all PWSSs requiring filtration. Rapid rate refers to the hydraulic loading of the filter. Slow sand filters and direct filtration are acceptable only under special conditions. GAC filter-absorbers may be used for the removal of organic contaminants and/or T&O producing contaminants. Typical bed lives are one to five years for this application but laboratory and/or pilot plant studies are recommended to confirm the GAC requirements since turbidity

and non-T&O organics can impact the adsorption capacity. GAC may be used in post-filter adsorbers, as a replacement or topping medium in existing filters, or in new filter-adsorbers. The former application is discussed in Section Q on Adsorption with GAC.

Pressure filters have the disadvantage of preventing easy inspection of the washwater efficiency which is the major reason why gravity filters are preferred for PWSSs. Pressure filters for treating groundwaters such as GWUI are approvable on a case by case basis only.

Canister bag or cartridge filter systems may be approved for treatment of groundwaters characterized as GWUI provided the effectiveness of the proposed system for removal or inactivation of *Giardia* cysts and for complying with turbidity requirements has been established. Appendix M of the USEPA *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface water Sources* (25) presents various approaches which can be utilized to demonstrate the effectiveness of alternate filtration technologies such as canister bag or cartridge systems. The canister bag or cartridge system physically removes particulates by trapping them on specially-designed material such as microporous ceramic elements or polypropylene woven fabrics. The bag or cartridge is installed in a cylindrical housing unit and operated typically in a down-flow manner. The bag or cartridge is removed from the housing unit and replaced when buildup of particulate matter results in excessive pressure drop across the unit. Engineering considerations include evaluating the necessity for pretreatment, pumping requirements, and the number, size, and arrangement of filter units necessary to treat a particular groundwater source.

1. RAPID RATE GRAVITY FILTERS

- a. PRETREATMENT - Pretreatment is required ahead of all rapid rate gravity filters.
- b. NUMBER - At least two units shall be provided. Where only two units are provided, each shall be capable of meeting the maximum design flow at the approved filtration rate. Where more than two filters are provided, the filters shall be capable of meeting the maximum design flow with one filter removed from service. Where declining rate filtration is provided, the variable aspect of filtration rates and the number of filters must be considered when determining the design capacity for the filters.

2. STRUCTURAL AND HYDRAULIC DETAILS

- a. FILTER BOX DEPTH - The minimum depth of the filter box shall be 10 ft (3 m).
- b. MINIMUM WATER DEPTH - The minimum water depth over the surface of the media shall be 3 ft (0.9 m) except for filters using an inlet split-rising control system.
- c. MAXIMUM WATER VELOCITY - The maximum velocity of the water in the pipes and conduits leading to the filters shall be 2 ft/sec (0.6 m/s).
- d. WALKWAYS - Walkways around the filters shall be not less than 2 ft (0.6 m) wide and not more than 3.5 ft (1.1 m) below the top of prefabricated filters. An access walkway is required for prefabricated filters so that operation and backwashing can be easily observed.
- e. OTHER CONSIDERATIONS - The filter system should be designed to provide for the following structural and hydraulic features:
 - 1) Vertical walls within the filter with no protrusion of the filter walls into the filter media,
 - 2) Cover by a superstructure,
 - 3) Head room to permit normal inspection and operation,
 - 4) Trapped effluent to prevent backflow of air to the bottom of filters,
 - 5) Curbs (4 in or 10.2 cm minimum) around the filters to prevent drainage into the filters,
 - 6) Prevention of flooding by providing an appropriately sized overflow,
 - 7) Cleanouts and straight alignments for influent pipes or conduits where solids loading is heavy, or following chemical softening,
 - 8) A washwater drain with capacity to carry maximum flow,
 - 9) Backwash piping located below the media,

- 10) Safety handrails between the filter and the walkways even if one or more filters are walled from the general gallery aisle,
 - 11) Construction to prevent cross connections and common walls between potable and non-potable water,
 - 12) Materials contacted by wetted GAC resistant to corrosion and abrasion losses,
- f. APPURTENANCES - The following items should be provided with every filter:
- 1) Influent and effluent sampling taps,
 - 2) Indicating loss-of-head gauge,
 - 3) Indicating and recording flow rate control,
 - 4) Provisions for draining the filter to waste with appropriate measures for backflow prevention,
 - 5) Effluent turbidimeter accurately reading to 0.1 NTU or less,
 - 6) The turbidimeter should have an alarm to signal unacceptable turbidity levels in the water being delivered to the distribution system with an option to shutdown the service pumps.
3. FLOW CONTROL - Any of several different kinds of flow control systems can be used depending upon the degree of automation desired, operator skills, and desired water quality. Designers should identify and validate the basis for their choice of control systems.
4. FILTER BOTTOMS AND STRAINER SYSTEMS - Block with gravel or false bottom, with or without gravel, underdrain systems are acceptable. The design of collection systems should minimize loss of head and assure an even distribution of washwater and an even rate of filtration over the entire area of the filter. The maximum velocity through underdrain fixtures to collect the filtered water and to uniformly distribute the backwash water shall be not less than 20 gpm/ft² (820 Lpm/m²) of filter area.

5. FILTER MEDIA

a. FILTER MEDIA QUALITY - Criteria for media quality shall conform to applicable AWWA Standards (4) for filtering material.

b. CRITERIA FOR FILTER TYPES

1) Single Media Beds - Silica sand is the approved filter material. Anthracite coal is approved only under special conditions.

a) For rapid sand filters, the minimum depth of sand is 27 in (0.7 m) and for anthracite coal is 42 in (1.1 m).

b) For rapid rate filters, the sand or anthracite coal shall have an effective size of 0.45 to 0.55 mm with a uniformity coefficient less than 1.65.

2) Dual Media Beds - Coal-sand filters shall consist of a coarse anthracite coal layer above a layer of fine sand. Some mixing of coal and sand at their interface is acceptable.

a) The minimum total depth of filter media should be 30 in (76 cm).

b) The coal layer should be about 18 in (46 cm) thick.

c) The fine sand layer should be 12 in (30 cm) minimum thickness. If 3 in (7.7 cm) of fine gravel support media is used with effective size of 0.8 to 2 mm with uniformity coefficient no greater than 1.7, 9 in (23 cm) of fine sand will be approved.

d) The sand and coal effective sizes shall be 0.4 to 0.55 mm and 0.8 to 1.1 mm with uniformity coefficients of less than 1.65 and 1.85, respectively. The effective size of anthracite coal when used as a cap shall be 0.8 to 1.2 mm with a uniformity coefficient less than 1.85.

- 3) Mixed Media Beds - Filter beds of this type typically contain a layer of anthracite coal, a layer of silica sand, and a layer of garnet sand or ilmenite. The relative size of the particles after backwash will result in a filter bed with pore spaces graded progressively from coarse to fine in the downward direction of filtration.

A media depth of 30 in (0.76 m) is typical and consists of 16.5 in (42 cm) of anthracite coal, 9 in (23 cm) of silica sand, and 4.5 in (11.4 cm) of garnet or ilmenite sand. Typical effective sizes are 0.8 to 1.1 mm, 0.35 to 0.5 mm, and 0.15 to 0.35 mm for coal, sand, and garnet, respectively. Use of other bed depths and media distributions must be approved by KDHE.

- 4) GAC Filter Adsorbers - GAC filter-adsorbers can be used by replacing a medium in an existing filter, capping an existing filter, or by the installation of a new filter-adsorber. The sand can be replaced in a single media filter or the coal in dual or mixed media filters. If sand or another medium is to be placed under GAC, care must be taken to size this medium so that it fluidizes properly relative to the GAC.

GAC medium replacement must result in a filter media configuration which is compatible for filtration and backwashing. GAC typically used is 15 to 30 in (0.38 to 0.76 m) of 12 x 40 mesh (effective size of 0.55 to 0.65 mm) or 8 x 30 mesh (effective size of 0.80 to 1.0 mm) placed over several inches of sand (effective size of 0.35 to 0.60 mm) for a dual media configuration.

c. FILTER MEDIA PLACEMENT

- 1) Prior to the placement of any filter material, the filter basin shall be cleaned thoroughly by means of a high-pressure water jet, sweeping, scrubbing, or equally effective means. The filter media shall be placed in the filter basin, backwashed and prepared for service in accordance with AWWA Standard B-100 (4). After all work related to placement of

media has been completed, and before the filter is placed in service, the entire filter shall be disinfected in accordance with AWWA Standard C-653 (4).

- 2) When the media is first installed, as many as ten backwashes may be necessary before the filter effluent is void of media fines.

6. UNDERDRAIN AND SUPPORT GRAVEL - Many filters use underdrain systems with graded gravel layers to support the media and to prevent its entry into the underdrain openings. The following guidelines should be followed to establish the gradations of the adjacent layers:

- a. Each gravel layer should be as uniform as possible, preferably retained between sieve openings that are apart by a ratio of two.
- b. The bottom-layer fine size should be 2 to 3 times the orifice diameter of the underdrain system.
- c. The top-layer fine size should be 4 to 4.5 times the effective size of the media to be retained.
- d. From layer to layer, the fine size of the coarser layer should be less than or equal to 2 times the fine size of the adjacent finer layer.
- e. Each layer should be at least 2 in (5 cm) thick or 3 times the coarse size of the layer, whichever is greater.

7. RATE OF FILTRATION - The rate of filtration shall be determined through consideration of such factors as raw water quality, degree of pretreatment, filter media, water quality control parameters, competency of operating personnel, and other factors as required by KDHE.

- a. NEW FILTER SYSTEMS - The following filtration rates are approved for new treatment plants which clarify, soften or remove hydrogen sulfide, iron and manganese, T&O, or trace organics:

Single Media	3.0 gpm/ft ² (123 Lpm/m ²)
Dual Media	4.0 gpm/ft ² (164 Lpm/m ²)
Mixed Media	5.0 gpm/ft ² (205 Lpm/m ²)

A filtration rate in excess of the above criteria can be used if shown to be satisfactory by pilot or in-plant testing.

- b. EXISTING FILTER SYSTEMS - For existing filter systems, the above listed filtration rate criteria for new filter systems may be used provided the following conditions are met:

- 1) Pre-filtration treatment facilities meet applicable KDHE requirements;
- 2) The filter system including support media, underdrain, and hydraulic controls are in satisfactory condition and meet applicable KDHE requirements;
- 3) KDHE approval to increase previously permitted rates of filtration is obtained.

- c. POLYMER USAGE - The use of polymeric filter aids should be evaluated for use in all filter systems.

- 8. BACKWASH - Provisions should be made for backwashing using:

- a. Filtered water provided at the required rate by washwater tanks, washwater pumps, from the high service main, or a combination of these. Duplicate washwater pumps are required unless an alternate means of obtaining water is available.
- b. A washwater regulator or valve on the main washwater line to obtain the desired rate of filter wash when the valve on each individual filter is wide open. The system design shall include provisions to prevent rapid changes in backwash water flow.
- c. A rate-of-flow indicator, preferably with a totalizer, on the operator console which is so located that the backwash flow rate can be easily read by the operator during the washing process. On small plants, where an operator console is not used, a flow gauge must be installed in the washwater line.
- d. Means to prevent accumulation of air in the filter washwater supply piping and pump between backwashes.

- e. Provisions for filtering to waste with appropriate measures for backflow prevention.

9. BACKWASH RATE AND DURATION

- a. The minimum rate of flow for filter backwashing without air scouring is 15 gpm/ft² (615 Lpm/m²) but a reduced rate may be acceptable for full depth anthracite or GAC filters. This rate corresponds to a temperature of 20°C (68°F).
- b. Each degree Celsius increase in temperature requires roughly a 2 percent increase in wash rate to prevent a reduction in bed expansion.
- c. For plants not equipped with turbidimeters to determine when to discontinue backwashing, the minimum duration of a filter wash without air scour is 15 min at the design rate of flow.

10. BACKWASH EQUIPMENT

- a. Use of storage at proper elevation or special washwater pumps is recommended. Use of water from high pressure mains for filter washing is not recommended except for standby service. This alternative may be approved under special conditions.
- b. Filter bottoms shall be designed to distribute the washwater evenly over the entire filter area and to withstand all imposed hydraulic and structural stresses.
- c. The bottom of the washwater trough should not be lower than the maximum level of the expanded media during washing.
- d. The top or edge of the washwater trough should be level.
- e. Washwater troughs should be spaced so that each serves an equal amount of filter surface area. The maximum horizontal travel of suspended solids to reach the washwater trough shall not exceed 3 ft (0.9 m).
- f. Washwater troughs should have a 2 in (5.1 cm) freeboard at the maximum rate of wash.

11. SURFACE WASH OR SUBSURFACE WASH - Surface or subsurface wash facilities are required except for filters used exclusively for iron and manganese removal. Air wash may be approved based on experimental data and operational experience. A surface wash system of fixed nozzles or a revolving type apparatus may be used to apply the washwater to the sand surface. However, rotary systems are generally preferred. All surface wash devices should be designed with:
 - a. Provisions for water pressures of at least 55 psi (380 kPa).
 - b. A vacuum breaker installed at least 1 ft (0.3 m) above high water level in the filter or other device to prevent back siphonage.
 - c. Spacing for the surface discharges are 2 to 3 ft (0.6 to 0.9 m) with the orifices about 2 in (5 cm) above the media and 4 to 8 in (10 to 20 cm) nozzle spacing for the fixed and revolving arms, respectively.
 - d. Rate of flow of 2.0 to 4.0 gpm (7.6 to 15 Lpm) and 0.5 to 1.0 gpm (1.9 to 3.8 Lpm) per square foot of filter area for fixed and revolving arms, respectively.
12. AIR SCOURING - Air scouring of the filter can be used in place of surface wash.
 - a. Air flow and concurrent washwater rates must be matched to fit the media type and size used. Typical air flow is 3 to 5 scf/min·ft² (0.9 to 1.5 m³/min) when the air is introduced in the underdrain; a lower air rate must be used when the air scour distribution system is placed above the underdrains. Generally, concurrent washwater rates are in the range of 4 to 7 gpm/sq ft (164 to 287 Lpm/m²).
 - b. Air scouring can be followed by a fluidization wash sufficient to restratify the media if this is desirable.
 - c. A method for avoiding excessive loss of filter media during backwashing must be provided. Some systems are equipped with a baffle arrangement; other systems use different washwater flow rates during periods of no concurrent air flow.

- d. Air must be free of contamination.
- e. Air scour distribution systems should be placed below the media and supporting bed interface; if placed at the interface the air scour nozzles shall be designed to prevent media from clogging the nozzles or entering the air distribution system.
- f. Piping for the air distribution system shall consist of a material of sufficient strength and rigidity to support the filter load without collapse and not be subject to erosion at its orifice opening due to the passage of air at high velocity.
- g. Air delivery piping shall not pass down through the filter media nor shall there be any arrangement in the filter design which would allow short circuiting between the applied unfiltered water and the filtered water.
- h. Consideration shall be given to maintenance and potential replacement of air delivery piping.
- i. The backwash delivery system must be capable of 15 gal/min·ft² (6.1 m/min); however, when air scour is provided the backwash rate must be variable and should not exceed 8 gal/min·ft² (3.3 m/min) unless operating experience shows that a higher rate is necessary to remove scoured particles from filter surfaces.
- j. The filter underdrains shall be designed to accommodate air scour piping when the piping is installed in the underdrain.

K. SOFTENING OR HARDNESS REMOVAL

1. REQUIREMENT - Softening should be considered for raw water having a total hardness exceeding 400 mg/L as CaCO₃, and total dissolved solids exceeding 500 mg/L. The alkalinity of the softened water should not be less than 65 mg/L expressed as CaCO₃. In general, the softening process selected must be based upon the mineral qualities of the raw water and the desired finished water quality in conjunction with requirements for disposal of sludge or brine wastes, cost of plant, cost of chemicals and plant location. Applicability of the process chosen shall be demonstrated.

2. RELATED CRITERIA - The applicable design criteria for presedimentation, rapid mixing, flocculation, sedimentation, and filtration (See Sections E to H and J, respectively) of surface water and/or GWUI are the same for lime or lime-soda ash softening. Criteria for solids contact units softening surface water and/or GWUI are given in Section H.
 - a. Softening chemicals and recycled sludge should be fed at the rapid mix basin along with the coagulant and/or coagulant aid as required for effective treatment. Typical sludge return values are 10 to 25 percent of the source water flow.
 - b. Softening chemicals may be added directly to the mixing compartment of solids contact units.
3. LIME SOFTENING PROCESS
 - a. Determinations should be made in the field for the CO₂ content of the raw water. If the concentration exceeds 10 mg/L and dissolved oxygen in the finished water will not create a corrosion problem, the possibility of CO₂ removal by aeration rather than by adding lime should be considered (see Section P on Aeration and Air Stripping).
 - b. Lime softening is best suited to waters containing calcium and magnesium carbonate hardness.
 - c. For groundwater containing chiefly calcium carbonate hardness, the following criteria are:
 - 1) The minimum detention times for the settling compartments of solids contact basins and conventional basins are 1.5 to 2.0 hr, respectively.
 - 2) The maximum pH should be 9.3 to 9.4 measured in the settling basin.
 - 3) Only single stage recarbonation is required.
 - d. Stabilization of water softened by lime treatment is required (See Section L on Stabilization).
 - e. Recycling of reclaimed lime should be considered for larger plants as an alternative to disposal.

4. LIME-SODA ASH SOFTENING PROCESS

- a. Lime-soda ash softening is applicable where both calcium and magnesium hardness are present in excessive amounts (magnesium greater than 40 to 50 mg/L as CaCO_3).
- b. The lime-soda ash softening process uses lime, Ca(OH)_2 , and soda ash, Na_2CO_3 , to precipitate hardness from solution. Carbon dioxide and carbonate hardness (calcium and magnesium bicarbonate) are complexed by lime. Noncarbonate hardness (calcium and magnesium sulfates or chlorides) requires the addition of soda ash for precipitation.
- c. For groundwater containing more than 25 mg/L magnesium, the required criteria are:
 - 1) The minimum detention times for the settling compartments of solids contact basins and conventional basins are 1.5 to 2.0 hr, respectively.
 - 2) Settling should also be provided between first and second stage recarbonation. The minimum basin detention time is 45 min with a maximum overflow rate of 1,500 gpd/ft² (61,500 Lpd/m²) and a maximum weir loading of 15,000 gpd/ft (186,000 Lpd/m).
- d. Stabilization of water softened by the lime-soda ash process is required (See Section L on Stabilization).

5. SPLIT TREATMENT - Under some conditions a lime-soda water treatment plant can be designed using split-treatment in which raw water is blended with lime-treated water to partially stabilize the water. Treatment plants designed to utilize split treatment should also contain facilities for further stabilization by other methods. Also, split treatment should be considered when the magnesium content of the water is high and the noncarbonate hardness content is insignificant. The magnesium content of the blended water should not exceed 40 mg/L if water heater fouling is to be prevented. The by-pass line should be valved, metered, and sized to carry the total plant flow. Also, if the by-passed water is surface water or GWUI clarification must be provided. Consultation with KDHE is required before proceeding with this process alternative.

6. CAUSTIC SODA SOFTENING

- a. Use of caustic soda in place of lime softening for low alkalinity waters results in only half the reduction of alkalinity as with the lime process.
- b. Other advantages of using caustic soda include its ease of storage, handling, and feeding along with less sludge production.
- c. Disadvantages of using caustic soda include its higher cost, and increases in the total dissolved solids and sodium content.

7. CATION EXCHANGE PROCESS - Cation exchange softening will only be approved on a case by case basis and the residual sodium and dissolved solids concentrations will be an important factor in this consideration. Silica gel resins should not be used for waters having a pH above 8.4 or containing less than 6 mg/L silica, and should not be used when iron is present. Iron, manganese, or a combination of the two, in the oxidized or unoxidized states, should not exceed 0.3 mg/L in the hard water treated by other cation exchange material. Pretreatment for iron or manganese may be necessary and should be carefully evaluated. Water having 5 NTU or more turbidity should not be applied directly to the ion exchange softener. When the applied water contains a chlorine residual, the cation exchange resin shall be a type that is not damaged by residual chlorine. Phenolic resins should not be used.

- a. DESIGN - The units may be pressure or gravity type, either upflow or downflow, and with automatic or manual regeneration. Automatic regeneration based on volume of water softened should be used unless manual regeneration is justified and approved by KDHE. A manual override shall be provided on all automatic controls. Units having a pipe which supplies water to the regeneration solution container also serving to siphon the solution to the softening unit will not be approved. All backwash, rinse, and air relief discharge pipes should be installed in a manner that will prevent back-siphonage.

- 1) Exchange Capacity - The design exchange capacity for hardness removal should be selected to minimize the resin regeneration and brine disposal requirements for the system.

- 2) Depth of Media - The depth of the exchange material should not be less than 3 ft (0.9 m).
 - 3) Flow Rates - Typical service flow rates for softening are 1 to 5 gpm/ft² (41 to 200 Lpm/m²) although higher rates are possible. The backwash rate should be selected to produce a bed expansion of no more than 100 percent.
 - 4) Freeboard - The freeboard will depend mainly upon the need of the resin for expansion during backwashing. Generally, the bottom of the washwater collector should be 2 ft (0.6 m) above the top of the resin on downflow units.
- b. BY-PASS - A by-pass should be provided for blending softened with unsoftened water to produce water of a desirable hardness. Totalizing meters must be installed on the by-pass line and on each softener unit. The by-pass line must have a shutoff valve and should have an automatic proportioning or regulating device. In some installations, it may be necessary to treat the by-passed water to obtain acceptable levels of iron and/or manganese in the finished water.
 - c. UNDERDRAINS AND SUPPORTING GRAVEL - These components should conform to criteria presented for rapid rate gravity filters.
 - d. CROSS-CONNECTION CONTROL - Backwash, rinse, and air relief discharge pipes should be installed in such a manner as to prevent any possibility of back-siphonage.
 - e. SAMPLING TAPS - Smooth nose sampling taps shall be located to provide samples of softener influent, effluent, and blended water. The sampling taps for blended water should be located at least 20 ft downstream from the point of blending. Sampling taps should be provided on the brine tank discharge piping.
 - f. BRINE DISTRIBUTION - Facilities should be included for even distribution of the brine over the entire surface of the upflow or downflow units.

- g. BRINE PUMP OR EDUCTOR - An eductor may be used to transfer brine from the brine tank to the softeners. If a pump is used, a brine measuring tank or means of metering should be provided to obtain proper dilution.
- h. BRINE AND SALT STORAGE TANKS
 - 1) Salt dissolving or brine tanks and wet salt storage tanks must be covered and corrosion resistant.
 - 2) The make-up water inlet must be protected from back-siphonage. Water for filling the tanks should be distributed over the entire surface by pipes above the maximum brine level in the tank. The tanks should be provided with an automatic declining level control system on the make-up water line.
 - 3) Wet salt storage basins must be equipped with manholes or hatchways for access and for direct dumping of salt from truck or railcar. Openings must be provided with raised curbs and watertight covers having overlapping edges similar to those required for finished water reservoirs.
 - 4) Overflows, where provided, must be protected with corrosion resistant screens and must terminate with either a turned-down bend having a proper free fall discharge or a self-closing flap valve.
 - 5) Two wet salt storage tanks or compartments designed to operate independently should be provided.
 - 6) The salt shall be supported on graduated layers of gravel placed over a brine collection system.
 - 7) Alternative designs which are conducive to frequent cleaning of the wet salt storage tank may be considered.
- i. SALT AND BRINE STORAGE CAPACITY - Total salt storage should have sufficient capacity to store in excess of 1.5 truckloads or carloads of salt, and provide for at least 30 days of operation.

- j. WASTE DISPOSAL - Suitable disposal must be provided for brine waste. Where the volume of spent brine must be reduced consideration may be given to using a part of the spent brine for a subsequent regeneration.
- k. CONSTRUCTION MATERIALS - Pipes and contact materials must be resistant to the aggressiveness of salt. Plastic and red brass are acceptable piping materials. Steel and concrete must be coated with a non-leaching protective coating which is compatible with salt and brine.
- l. HOUSING - Bagged salt and dry bulk salt storage shall be enclosed and separated from other operating areas in order to prevent damage to equipment.

L. **STABILIZATION** - Water that is unstable due either to natural causes or to treatment processes should be stabilized. Natural causes refer to chemical and microbial activity which results in water quality changes usually in treated water storage and/or the distribution system. This includes corrosion caused by galvanic or biochemical action. Unstable water due to treatment refers to the saturation of water with respect to calcium carbonate. Water saturated with CaCO_3 is neither depositing nor aggressive. Water oversaturated is unstable and can deposit a scale while water undersaturated is unstable and can be corrosive.

- 1. RECARBONATION OF SOFTENED WATER - For treatment of low-magnesium water where excess lime addition is not required, single-stage recarbonation is used. Carbon dioxide is added to reduce the pH to 8.5 to 9.0. For treatment of high-magnesium water where excess lime is required, two-stage recarbonation is sometimes used. Following first-stage treatment, carbon dioxide is added to reduce the pH to 10.0 to 10.6. During second-stage treatment, carbon dioxide is added to reduce the pH to 8.4 to 8.6. Liquid carbon dioxide addition is recommended. Submerged gas burners are not approved for new installations.

a. Recarbonation basin design should provide:

- 1) A total detention time of 20 min.

- 2) Two compartments, with a depth that will provide a diffuser submergence of not less than 7.5 ft (2.3 m) nor greater submergence than recommended by the manufacturer as follows:
 - a) A mixing compartment having a detention time of at least 3 min.
 - b) A reaction compartment.
 - b. Adequate precautions must be taken to prevent carbon dioxide from entering the plant from the recarbonation process.
 - c. Provisions should be made for draining the recarbonation basin and removing accumulated sludge.
2. SPLIT TREATMENT - Split-treatment for partial control of stability is feasible but provisions must be made for the clarification and disinfection needs of the combined waters.
3. ION EXCHANGE - Unstable water created by the ion exchange process should be stabilized using the appropriate chemicals for the type of instability produced.
4. POLYPHOSPHATES - Polyphosphates may be approved for sequestering calcium after softening. Requirements accompanying its use include:
 - a. Phosphate chemicals must meet the applicable AWWA Standards (4) .
 - b. The stock phosphate solution should be covered and disinfected by carrying approximately 10 mg/L free chlorine residual. Phosphate solutions having a pH of 2.0 or less may be exempt from this requirement by KDHE.
5. CARBON DIOXIDE REDUCTION BY AERATION - The carbon dioxide content of an aggressive water may be reduced by aeration (see Section P on Aeration and Air Stripping) .
6. WATER INSTABILITY DUE TO BIOCHEMICAL ACTION IN THE DISTRIBUTION SYSTEM - Unstable water resulting from the bacterial decomposition of organic matter (especially in mains), the biochemical action within tubercles, and the reduction of sulfates and sulfites should be prevented by maintaining a chlorine residual throughout the distribution system.

7. OTHER TREATMENT - Other treatment for controlling corrosive waters by the use of sodium silicate and sodium bicarbonate may be used where necessary. Any proprietary compound must receive the approval of KDHE before use. Chemical feeders must be approved by KDHE (see Chapter IX on Chemical Storage, Handling, and Disposal).
8. CONTROL OF STABILITY - Laboratory equipment shall be provided for determining the effectiveness of stabilization treatment.

M. DISINFECTION

Disinfection requirements depend upon the source of the supply. Surface water or GWUI sources must use a treatment approach based on CT calculations to achieve a three log removal of *Giardia lamblia* and a four log removal of viruses. This treatment approach will involve pretreatment processes prior to filtration along with the required disinfection of all PWSSs. In addition, there are monitoring requirements for disinfectant residuals and turbidity which if violated could require additional treatment above that determined acceptable based solely on CT calculations.

Single or multiple disinfectants can be used to meet any of these requirements. Approved disinfectants include free chlorine, combined chlorine, chlorine dioxide, and ozone. The use of heat, extremes in pH, metals, surfactants, potassium permanganate, hydrogen peroxide, iodine, bromine, or ultraviolet light as disinfectants are not permissible. Design considerations for gas chlorination facilities are addressed in Chapter IX.

1. CT REQUIREMENTS - The basis for determining the acceptability of a treatment scheme is to evaluate the composite CT for the system under two extremes of operation. These are summer and winter operations at maximum hourly flow. For new treatment plants, CTs are calculated using these temperature extremes for the design values of detention times and disinfectant residuals. For upgrading existing facilities, CTs are calculated using the existing plant data and new design values for add-ons or modified treatment units. In both cases, these results are compared with USEPA CT requirements to determine if the required log removals for *Giardia lamblia* and viruses are achieved (25).
2. GROUNDWATER (EXCLUDING GWUI)
 - a. KDHE must determine if a groundwater resource is not GWUI (or exempt from the SWTR).

- b. All supplies shall be disinfected before delivery to the distribution system.
 - c. Water from several wells may be combined to facilitate the disinfection process.
 - d. A sample collecting tap of the disinfected water shall be located before it enters the distribution system and at least 10 pipe diameters downstream from the point of disinfection or following the complete mixing of the disinfectant with the treated water.
 - e. Criteria for chlorine residuals at distant points in the distribution system are:
 - 1) Minimum free residual chlorine at the ends of the water distribution system shall not be less than 0.2 mg/L, or
 - 2) Combined chlorine residual at the ends of the distribution system shall not be less than 1.0 mg/L.
3. SURFACE WATER AND GWUI - Disinfection of these sources can be accomplished using one or more disinfectants at one or more points in the treatment train, storage, and distribution system. The choice of disinfectant(s) and location(s) will depend on the designer's concern for eliminating operational problems associated with biological fouling and T&Os, and needs to meet DBPs, MCLs, microbial removal and inactivation requirements, and to maintain a minimum disinfectant residual throughout the PWSS. All water treatment plants which serve more than 10,000 persons and use surface water as a source of supply with chlorine as the primary disinfectant should consider maintaining a combined chlorine residual throughout the distribution system in order to meet DBP restrictions.
- a. PREDISINFECTION - Disinfection has historically been conducted by Kansas PWSSs to control operational problems associated with biological fouling and T&O in process stages such as presedimentation basins. However, due to recent stringent regulatory limitations on DBPs in the finished water, predisinfection is no longer a viable option for many systems. Current proposals

by systems to conduct pre-disinfection will be evaluated by KDHE on a case by case basis. Relevant factors for evaluating such a proposal include the following:

- 1) Impact on formation of DBPs in a particular source water and whether the PWSS will be able to comply with all applicable regulatory limitations on DBPs.
- 2) Purpose of pre-disinfection and whether other alternative operational measures can achieve the desired objective.

b. PRIMARY DISINFECTION - Primary disinfection is required in order to control biological fouling, to accomplish microbial inactivation within the treatment plant, and to maintain a minimum disinfectant residual throughout the distribution system. The points of application are usually ahead of the filters to control slime growth on the filter media and after filtration prior to storage in the clear well to protect the water during storage and to produce the desired residual in the distribution system. Criteria for primary disinfection includes:

- 1) Minimum contact time required by the SWTR for achieving the necessary level of inactivation of *Giardia lamblia* and virus as expressed in terms of a CT value. The required contact time is dependent on several factors including the disinfectant residual concentration, temperature, and pH. The contact time required for ozone inactivation of microbes must be determined by pilot or in-plant studies (See part M,4 below).
- 2) Regulatory limitations on DBPs in the finished water.
- 3) Maintaining chlorine residuals at distant points in the distribution system:
 - a) Minimum free residual chlorine at the ends of the water distribution system shall not be less than 0.2 mg/L, or
 - b) Combined chlorine residual at the ends of the distribution system shall not be less than 1.0 mg/L.

- 4) Chlorinator capacity for primary disinfection should not be less than 10 mg/L at maximum flow and shall vary based on location and treatment type.
- c. SUPPLEMENTAL DISINFECTION - Regardless of the primary disinfectant used, chlorination facilities may be required for repumped storage reservoirs in the distribution system. The same requirement will apply to booster-pump stations in the distribution system. Other chlorination stations may be required to maintain satisfactory chlorine residuals in some distribution systems.
- d. CHLORAMINES - Guidelines for treatment using chloramines are:
- 1) Sufficient ammonia or an ammonium compound should be added to convert free chlorine to the combined form at a location beyond the first point of primary disinfection where adequate mixing can occur. A $\text{Cl}_2:\text{NH}_3\text{-N}$ applied weight ratio of 3:1 to 5:1 is generally considered the optimum range for formation of monochloramine under common chloramination treatment conditions. Lower ratios tend to favor nitrification in the distribution system; higher ratios favor the formation of di- and trichloramine that can potentially cause taste-and-odor problems. Ammonia or an ammonium compound should be fed after the chlorine but before the treated water enters the clearwell.
 - 2) Careful consideration must be given to the pH of the treated water, the average residence time in the distribution system, and other factors in setting the combined chlorine residual for the water delivered to the distribution system. The combined form of chlorine is much less efficient than free chlorine as a disinfectant, and a correspondingly higher concentration must be maintained to accomplish the desired degree of protection from pathogens and to prevent biological growths in the distribution system. This is reflected in the larger required CT value for chloramine disinfection as compared to free chlorine at the same pH and water temperature to achieve a desired level of inactivation of *Giardia lamblia* or viruses (25).

4. OZONATION - As a minimum, bench scale studies shall be conducted to determine the minimum and maximum ozone dosages for disinfection, and T&O control (see Section N) unless there is sufficient data available from tests performed on the same water source. More involved pilot plant studies shall be conducted when necessary to document benefits and THM precursor removal effectiveness. Consideration shall be given to multiple points of ozone addition. Pilot studies shall be conducted for all surface waters unless there is sufficient data available from studies performed on the same water source. Extreme care must be taken during bench and pilot scale studies to ensure accurate results. Particularly sensitive measurements include gas and water flow rates, and ozone concentrations. The following items shall be addressed in the design:

a. FEED GAS PREPARATION

- 1) General - Feed gas can be air, high purity oxygen, or oxygen enriched air. Air handling equipment on conventional low pressure air feed systems shall consist of an air compressor, water/air separator, refrigerant dryer, heat reactivated desiccant dryer, and particulate filters. Some package ozonation systems for small plants may work effectively operating at high pressure without the refrigerant dryer and with a heatless desiccant dryer. In all cases the designer must ensure that the maximum dew point of minus 60°C (-76 °F) will not be exceeded at any time. For oxygen-feed systems, dryers typically are not required.

2) Air Compression

- a) Air compressors shall be of the liquid-ring or rotary lobe, oil-less, positive displacement type or dry rotary screw compressors. Generally, dry rotary screw compressors are utilized by large systems. However, liquid ring compressors have been installed on some large systems, also.
- b) The air compressors shall have the capacity to simultaneously provide for maximum ozone demand, provide the air flow required for purging the desiccant dryers (where required) and allow for standby capacity.

- c) Air feed for the compressor shall be drawn from a point protected from rain, condensation, mist, fog, and contaminated air sources to minimize the moisture and hydrocarbon content of the air supply.
- d) A compressed air after-cooler and/or entrainment separator with automatic drain shall be provided prior to the dryers to reduce the water vapor.
- e) A back-up air compressor must be provided so that ozone generation is not interrupted in the event of a breakdown.

3) Air Drying

- a) Dry, dust-free and oil-free feed gas must be provided to the ozone generator. Dry gas is essential to prevent formation of nitric acid, to increase the efficiency of ozone generation, and to prevent damage to the generator dielectrics. Sufficient drying to a maximum dew point of minus 60°C (-76°F) must be provided at the end of the drying cycle.
- b) Drying for high pressure systems may be accomplished using heatless desiccant only. For low pressure systems, a refrigeration air dryer in series with heat-activated desiccant dryers shall be used except with a chilled water aftercooler. In the latter case, the chilled water system serves as the cooling water supply for the ozone generators and for the compressed air aftercoolers.
- c) A refrigeration dryer capable of reducing inlet air temperature to 4°C (40°F) shall be provided for low pressure air preparation systems. The dryer can be of the compressed refrigerant type or chilled water type.

- d) For heat-reactivated desiccant dryers, the unit shall contain two desiccant filled towers complete with pressure relief valves, two four-way valves, and a heater. In addition, external type dryers shall have a cooler unit and blowers. The size of the unit shall be such that the specified dew point will be achieved during a minimum adsorption cycle time of 16 hours while operating at the maximum expected moisture loading conditions.
- e) Multiple air dryers shall be provided so that the ozone generation is not interrupted in the event of dryer breakdown.
- f) Each dryer shall be capable of venting dry gas to the atmosphere, prior to the ozone generator, to allow startup when other dryers are on-line.

4) Air Filters

- a) Air filters shall be provided on the suction side of the air compressors, between the air compressors and the dryers and between the dryers and the ozone generators.
- b) The filter before the desiccant dryers shall be of the coalescing type and be capable of removing aerosol and particulate larger than 0.3 microns in diameter. The filter after the desiccant dryer shall be of the particulate type and be capable of removing all particulate greater than 0.1 microns in diameter, or smaller if specified by the generator manufacturer.

5) Air Preparation Piping - Piping in the air preparation system can be common grade steel, seamless copper, stainless steel, or galvanized steel. The piping must be designed to withstand the maximum pressure in the air preparation system.

b. OZONE GENERATOR

1) Capacity

- a) The production rating of the ozone generators shall be stated in mass per time (kg/day or lbs/day) and energy per mass (kWh/kg or HP-h/lb) at a maximum cooling water temperature and maximum ozone concentration.
- b) The design shall ensure that the minimum concentration of ozone in the generator exit gas will not be less than one percent (by weight), unless the system is specifically designed to operate at less than one percent.
- c) Generators shall be sized to have sufficient reserve capacity so that the system does not operate at peak capacity for extended periods of time. This can result in premature breakdown of the dielectrics. Generators should not be operated at more than 90% of rated capacity.
- d) The production rate of ozone generators will decrease as the temperature of the coolant increases. If there is to be a variation in the supply temperature of the coolant throughout the year, then curves or other data shall be used to determine production changes due to the temperature change of the supplied coolant. The design shall ensure that the generators can produce the required ozone at maximum coolant temperature.
- e) Appropriate ozone generator backup equipment must be provided.

- 2) Electrical - The generators can be low, medium, or high frequency type. Specifications shall require that the transformers, electronic circuitry, and other electrical hardware be proven, high quality components designed for ozone service.

- 3) Cooling - The required water flow to an ozone generator varies with the ozone production. Normally, unit design provides a maximum cooling water temperature rise of 2.8°C (5°F) except where a chilled water cooling system is used. The cooling water must be properly treated to minimize corrosion, scaling, and microbiological fouling of the water side of the tubes. A closed loop cooling water system is often used to insure that proper water conditions are maintained. Where cooling water is treated, cross-connection control shall be provided to prevent contamination of the PWSS.
 - 4) Materials - To prevent corrosion, the ozone generator shell and tubes shall be constructed of 316L stainless steel.
- c. OZONE CONTACTORS - The selection or design of the contactor and method of ozone application depends on the purpose for which the ozone is to be used.
- 1) Bubble diffusers
 - a) Where disinfection is the primary application a minimum of two contact chambers, each equipped with baffles to prevent short-circuiting and induce countercurrent or cocurrent flow, shall be provided. Ozone shall be applied using porous-tube or dome diffusers.
 - b) The minimum contact time shall be ten minutes. A shorter contact time may be approved by KDHE if justified by appropriate design and CT considerations.
 - c) For ozone applications in which precipitates are formed, such as with iron and manganese removal, porous diffusers should be used with caution.
 - d) Where T&O control is of concern, multiple application points and contactors shall be considered.

- e) Contactors should be separate closed vessels. The contactor must be kept under negative pressure and sufficient ozone monitors shall be provided to protect worker safety. Placement of the contactor where the entire roof is exposed to the open atmosphere is recommended. In no case shall the contactor roof be a common wall with a separate room above the contactor.
- f) Large contact vessels should be made of reinforced concrete. All reinforcement bars shall be covered with a minimum of 3.0 in (7.6 cm) of concrete. Smaller contact vessels can be made of stainless steel or other material which will be stable in the presence of residual ozone and ozone in the gas phase above the water level.
- g) Where necessary a system shall be provided between the contactor and the off-gas destruct unit to remove froth from the air and return it to the contactor or another location acceptable to KDHE. If foaming is expected to be excessive, then a potable water spray system shall be placed in the contactor head space.
- h) All openings into the contactor for pipe connections, hatchways, etc., shall be properly sealed using welds or ozone resistant gaskets such as Teflon or Hypalon.
- i) Multiple sampling ports shall be provided to enable sampling of each compartment's effluent water and to confirm CT calculations.
- j) A pressure/vacuum relief valve shall be provided in the contactor and piped to a location where there will be no damage to the destruction unit.
- k) The diffusion system should work on a countercurrent or cocurrent basis with respect to the ozone and water feeds.

- 1) The depth of water in bubble diffuser contactors should be a minimum of 18 ft (5.5 m) unless a smaller depth is justified by transfer efficiency considerations. The contactor should also have a minimum of 3.0 ft (0.9 m) of freeboard to allow for foaming.
- m) All contactors shall have provisions for cleaning, maintenance, and drainage of the contactor. Each contactor compartment shall also be equipped with an access hatchway.
- n) Aeration diffusers shall be fully serviceable by either cleaning or replacement.
- 2) Other Contactors - Other contactors, such as the venturi or aspirating turbine mixer contactor, may be approved by KDHE provided that adequate ozone transfer is achieved and the required contact times and residuals can be met and verified.

d. OZONE DESTRUCTION UNIT

- 1) A system for treating the final off-gas from each contactor must be provided in order to meet applicable safety and air quality standards. Acceptable systems include thermal destruction and thermal/catalytic destruction units
- 2) In order to reduce the risk of fires, the use of units that operate at lower temperatures is encouraged, especially where high purity oxygen is the feed gas.
- 3) The maximum allowable ozone concentration in the discharge is 0.1 ppm (by volume) based on the maximum recommended limit for worker exposure for eight hours or more.
- 4) At least two units shall be provided which are each capable of handling the entire gas flow.
- 5) Exhaust blowers shall be provided in order to draw off-gas from the contactor into the destruct unit.

- 6) Catalysts must be protected from froth, moisture, and other impurities which may harm the catalyst. Demisters are typically used to provide this protection.
 - 7) The catalyst and heating elements shall be located where they can easily be reached for maintenance
- e. PIPING MATERIALS - Only low carbon 304L and 316L stainless steels shall be used for ozone service with 316L the preferred.
- f. JOINTS AND CONNECTIONS
- 1) Connections on piping used for ozone service are to be welded where possible; otherwise, flanged connections shall be used.
 - 2) Connections with meters, valves, or other equipment are to be made with flanged joints with ozone resistant gaskets, such as Teflon or Hypalon. Screwed fittings shall not be used because of a tendency to leak.
 - 3) A positive closing plug or butterfly valve plus a leak-proof check valve shall be provided in the piping between the generator and the contactor to prevent moisture reaching the generator.
- g. INSTRUMENTATION
- 1) Pressure gauges shall be provided at the discharge from the air compressor, at the inlet to the refrigeration dryers, at the inlet and outlet of the desiccant dryers, at the inlet to the ozone generators and contactors, and at the inlet to the ozone destruction unit.
 - 2) Electric power meters should be provided for measuring the electric power supplied to the ozone generators. Each generator shall have a trip which shuts down the generator when the wattage exceeds a certain preset level.

- 3) Dew point monitors shall be provided for measuring the moisture of the feed gas from the desiccant dryers. Because it is critical to maintain the specified dew point, it is recommended that continuous recording charts be used for dew point monitoring which will allow for proper adjustment of the dryer cycle. Where there is potential for moisture entering the ozone generator from downstream of the unit or where moisture accumulation can occur in the generator during shutdown, the installation of post-generator dew point monitors should be considered.
- 4) Flow meters shall be provided for measuring inlet gas at the application point to each contactor. Additional recommended flow monitoring points include air flow from the desiccant dryers to each of the ozone generators and purge air flow to the desiccant dryers.
- 5) Temperature gauges shall be provided for the inlet and outlet of the ozone cooling water and the inlet and outlet of the ozone generator feed gas, and, if necessary, for the inlet and outlet of the ozone power supply cooling water.
- 6) Water flow meter shall be installed to monitor the flow of cooling water to the ozone generators and, if necessary, to the ozone power supply.
- 7) Ozone monitors shall be installed to measure ozone concentrations in both the feed-gas and off-gas from the contactor and in the off-gas from the destruct unit. For disinfection systems, monitors shall also be provided for monitoring ozone residuals in the water. The number and location of ozone residual monitors shall be such that the amount of time that the water is in contact with the ozone residual can be determined.
- 8) A minimum of one ambient ozone monitor shall be installed in the vicinity of the contactor and a minimum of one shall be installed in the vicinity of the generator. Ozone monitors shall also be installed in any areas where ozone gas may accumulate.

h. ALARMS - The following alarm/shutdown systems should be considered at each installation.

- 1) Dew Point Shutdown/Alarm - This system should shut down the generator in the event the system dew point exceeds minus 60°C (-76°F).
- 2) Ozone Generator Cooling Water Flow Shutdown/Alarm - This system should shut down the generator in the event that cooling water flow decreases to the point that generator damage could occur.
- 3) Ozone Power Supply Cooling Water Flow Shutdown/Alarm - This system should shut down the power supply in the event that cooling water flow decreases to the point that damage could occur to the power supply.
- 4) Ozone Generator Cooling Water Temperature Shutdown/Alarm - This system should shut down the generator if either the inlet or outlet cooling water exceeds a certain preset temperature.
- 5) Ozone Power Supply Cooling Water Temperature Shutdown/Alarm - This system should shut down the power supply if either the inlet or outlet cooling water exceeds a certain preset temperature.
- 6) Ozone Generator Inlet Feed-Gas Temperature Shutdown/Alarm - This system should shut down the generator if the feed-gas temperature is above a preset value.
- 7) Ozone Generator Inlet Feed-Gas Flow Shutdown/Alarm - The alarm should sound when the feed-gas flow to the generators is less than a preset value.
- 8) Ambient Ozone Concentration Shutdown/Alarm - The alarm should sound when the ozone level in the ambient air exceeds 0.1 ppm or a lower value chosen by the water supplier. Ozone generator shutdown should occur when ambient ozone levels exceed 0.3 ppm (or a lower value) in either the vicinity of the ozone generator or the contactor.

- 9) Ozone Destruct Temperature Alarm - The alarm should sound when temperature exceeds a preset value.

i. SAFETY

- 1) The maximum allowable ozone concentration in the air to which workers may be exposed must not exceed 0.1 ppm (by volume).
- 2) Noise levels resulting from the operating equipment of the ozonation system shall be controlled to within acceptable limits by special room construction and equipment isolation.
- 3) High voltage and high frequency electrical equipment must meet current electrical and fire codes.
- 4) Emergency exhaust fans must be provided in the rooms containing the ozone generators to remove ozone gas if leakage occurs.
- 5) A portable purge air blower that will remove residual ozone in the contactor prior to entry for repair or maintenance should be provided.

j. CONSTRUCTION CONSIDERATIONS

- 1) Prior to connecting the piping from the desiccant dryers to the ozone generators, the air compressors should be used to blow the dust out of the desiccant.
- 2) The contactor should be tested for leakage after sealing the exterior. This can be done by pressurizing the contactor and checking for pressure losses.
- 3) Connections on the ozone service line should be tested for leakage using the soap-test method.

N. TASTE AND ODOR CONTROL

1. REQUIREMENT - All surface water supplies may have periodic T&O problems and should provide means for their prevention and control. Attention should be given to these potential problems in the management of the watershed, in the design of the treatment plant, and on

the basis of past experience with the supply. Plants treating waters that are known to have T&O problems should be provided with equipment that allows several of the available control processes to be used so that the operator will have maximum flexibility in the plant's operation. Also, pilot plants or in-plant studies may be necessary to deal with severe T&O problems.

2. CHLORINE AND CHLORINE DIOXIDE - Historically, prechlorination has been used for T&O control. However, DBP restrictions may preclude this option in the future for some applications. Water sources which contain more than 1.0 mg/L phenol will require special attention for T&O control. Chlorine dioxide has been generally recognized as a treatment agent for tastes caused by industrial wastes, such as phenols. Chlorine dioxide byproduct removal should be considered.
3. HYDROGEN SULFIDE REMOVAL - Hydrogen sulfide in amounts greater than 0.2 mg/L imparts an unpleasant T&O to the water. Removal can be achieved by aeration and chlorination and followed by at least 2 hour detention and filtration. If lime-soda ash softening is being practiced, the detention period for H₂S removal must precede any rise in pH due to the lime addition.
4. PAC - PAC should be added prior to coagulation to provide maximum contact time for T&O removal. However, flexibility to allow the addition of carbon at several points is also preferred.
 - a. POINT OF ADDITION - In selecting the point of PAC addition, consideration should be given to the following:
 - 1) Enhancing contact between the carbon and water being treated by the provision of adequate mixing.
 - 2) Allowing sufficient contact time for adsorption of the particular contaminant of concern. The required contact time is a function of the characteristics and concentration of the molecule to be adsorbed, the dosage of the PAC, and the presence of any competing organics in the water.
 - 3) Minimizing interference of other treatment chemicals with the adsorption process. Activated carbon will chemically reduce compounds such as chlorine, chlorine dioxide,

ozone, and permanganate. This reduction process impairs the adsorptive capacity of the carbon for certain organic compounds such as phenols as well as increasing disinfectant demand.

- 4) Recommended points of addition of PAC are the inlets to the rapid mix, flocculator, and sedimentation units and the outlet of the sedimentation unit. PAC may be used before the filters to remove chlorine dioxide and/or DBPs.
- b. RATE OF APPLICATION - The required dosage of carbon in a water treatment plant depends upon the T&O involved but the upper limit is controlled by the carryover to the filters at the highest carbon feed rate. Provisions should be made for adding 0.1 to 40 mg/L although higher doses could be needed.
- c. METHOD OF APPLICATION - Carbon should be added as a slurry to the untreated water. This approach requires mixing to disperse the carbon throughout the stock slurry. A dry feeder measures the carbon, and an agitator mixes the carbon with the water. The PAC concentration in the slurry should not exceed 0.5 to 1.0 lb/gal (60 to 120 g/L) to reduce settling and to maintain fluid conditions suitable for handling. Once wetted the slurry can be pumped into the feed lines with periodic water flushing or transferred by eduction to prevent caking. Slurry storage is recommended for larger PWSSs to accommodate truck or railcar quantities. Continuous agitation equipment is necessary to keep the PAC from depositing in the slurry storage tank and to aid in wetting the PAC.

Provisions should be made to minimize dust. A separate room should be provided for carbon feed installations. Carbon feeder rooms should be equipped with explosion-proof electrical outlets, lights, and motors.

5. GAC - See Section J on Filtration and Section Q on Adsorption with GAC for related design criteria.
6. POTASSIUM PERMANGANATE - Application of potassium permanganate may be considered providing the treatment is so designed that the permanganate and manganese dioxide does not impart a visible color to the finished water in

the clearwell. The application point should be at the rapid mix in conjunction with coagulant addition or upstream at the raw water intake.

7. Copper Sulfate - Application of copper sulfate to surface impoundments to prevent and/or control algae where T&O problems develop should be done at regular intervals. The level of copper in the finished water should not exceed the treatment technique level of 1.3 mg/L. All copper sulfate treatment schemes should be coordinated with local KDWP officials.

a. RATE OF APPLICATION - 5.4 lbs (2.5 kg) of blue crystals per acre of surface. This rate of application will not kill the indigenous fish.

b. METHOD OF APPLICATION - Apply as uniformly as possible over the surface of the lake using one of the following techniques:

1) Hold a coarse weave burlap sack containing the crystals along-side a moving boat and crisscross the lake surface in order to obtain the uniform distribution of the released chemical.

2) Use a solution barrel, pump, and pressure spray mounted on a barge. By splitting the pump suction (one line to the lake and one to the barrel), the amount of solution sprayed per unit of lake area can be easily adjusted.

c. SCHEDULE OF APPLICATION

1) The schedule of application should be based on site specific conditions and the rate of algal regrowth. The Office of Science and Support of KDHE provides training in algae identification and will assist PWSSs develop an algal monitoring program and an optimum schedule for application of copper sulfate for control of T&O problems.

2) Best results are obtained when initial application is made in late April or early May and continued until the latter part of August or early September.

- 3) The initial application may be made at any time during the summer months, but if done late in August or early September, the kill may be excessive, thus possibly contributing to taste and odor problems or a drop in the dissolved oxygen content of the lake.
- d. SHELTERED AREAS - Where aquatic weeds provide sheltered areas which support overgrowth of algae, application of copper sulfate to the adjacent lake surface will not correct the condition. Therefore, a special effort will have to be made to adequately treat these areas.
8. OZONE - Ozonation can be used as a means of T&O control. Adequate contact time must be provided to complete the chemical reactions involved. Ozone is generally more desirable for treating water with high threshold odors. See Section M on Disinfection).
9. OTHER METHODS - The decision to use any other methods of T&O control should be made only after careful laboratory and/or pilot plant tests, and consultation with KDHE.

O. IRON AND MANGANESE REMOVAL

The control of iron and manganese requires the selection of one or more treatment processes which are designed specifically for this purpose and which will meet specific local conditions as determined by engineering investigations. It may be necessary to conduct laboratory tests or operate a pilot plant to facilitate these investigations. Consideration should be given to adjusting the pH of the raw water to optimize the desired chemical reactions. KDHE must approve the proposed treatment scheme.

1. REMOVAL BY OXIDATION, DETENTION, AND FILTRATION

- a. DESCRIPTION OF REMOVAL PROCESS - This removal process depends on the formation of insoluble forms of iron and manganese during oxidation with the precipitates removed by subsequent processes: The ferrous iron ion, Fe^{2+} , is oxidized to the ferric ion, Fe^{3+} , and precipitated as ferric hydroxide, $\text{Fe}(\text{OH})_3$; the manganous manganese ion, Mn^{2+} , is oxidized to the tetravalent manganese ion, Mn^{4+} , and precipitated as manganese dioxide, MnO_2 . Oxidation may be accomplished through aeration using gravity, forced or induced draft aerators, or by chemical

oxidation with chlorine, chlorine dioxide, ozone, or potassium permanganate. In some cases, catalysts have been used to speed up the oxidation processes.

- b. FACTORS INFLUENCING REACTION - The oxidation of iron and manganese with oxygen as the oxidizing agent is strongly dependent on pH. While the reaction rate for oxygenation of ferrous iron occurs very rapidly above a pH of 7.5, the rate of oxygenation of manganous manganese is relatively slow below a pH of 9.5. The oxygenation of manganous manganese depends not only on pH and other variables but is further complicated by autocatalysis by manganese dioxide.

Some manganese removal may result by sorption on ferric hydroxide or hydrated oxide precipitates. Oxidation of iron and manganese with chlorine or permanganate is quite rapid at pH 7 or higher. The oxidation of iron and manganese produces hydrogen ions which consume alkalinity. If insufficient alkalinity is present, the pH may decrease with a concurrent decrease in the rate of the reaction. Lime or NaOH addition may be required for pH adjustment.

- c. DOSAGE CONSIDERATIONS - The removal system should be designed to provide at least the stoichiometric oxidant requirements for iron and manganese removal assuming the highest anticipated influent concentrations with the application of an appropriate safety factor. When chlorine is used as the oxidant, a dosage somewhat more than the theoretical stoichiometric requirements should be provided for due to the potential of chlorine side reactions. However, the actual amount of permanganate required may be less because of the adsorptive and catalytic effects of manganese dioxide.

- d. REACTION TIME CONSIDERATIONS - The reaction time required to accomplish the complete formation of insoluble forms of iron and manganese is dependent on the particular oxidant and the chemical environment in which the oxidation and precipitation occur. In particular, oxidation kinetics are strongly pH and species dependent. Sufficient reaction time must be provided for prior to filtration by the use of a separate detention basin, sedimentation basin, or solids contact reactor.

The separate detention basin should be designed with baffling to prevent short circuiting. The required reaction time for a particular oxidation system shall be determined based on the kinetic data and operating parameters after consultation with KDHE. A minimum reaction time of at least 20 minutes shall be provided if oxidation is accomplished through aeration.

- e. SEDIMENTATION BASINS - Sedimentation basins should be provided when treating water high in iron and/or manganese or where chemical coagulation is used to reduce the load on the filters. Provisions for sludge removal must be made.
- f. FILTRATION - Filters should be provided which conform to KDHE requirements given in Section J on Filtration.

2. REMOVAL BY MANGANESE ZEOLITE (GREENSAND) FILTRATION - In this process potassium permanganate is fed continuously to the influent of a manganese zeolite filter. It is more applicable to the removal of manganese than of iron because of economic considerations.

- a. The permanganate should be fed to the raw water as far ahead of the filter as possible and not immediately before the filter. A long reaction time is preferred. A minimum permanganate feeding capability of 1.5 mg/L for each mg/L of iron, plus 2.5 mg/L for each mg/L of manganese should be provided.
- b. Use of other oxidizing agents to meet part of the oxidant demand is recommended. Also, post-chlorination may be necessary so that the required residual can be maintained in the distribution system. If a supplemental chlorine solution is used, not more than 0.4 mg/L of free residual chlorine should pass through the filter.
- c. Sufficient capacity for the feeding of other oxidants and/or the permanganate shall be provided.
- d. A cap of anthracite media of 6 in (15 cm) is recommended over the manganese greensand. Other media types may be approved if the capability of developing and maintaining the manganic oxide coating can be demonstrated. The total filter media depth should not be less than 27 in (69 cm). If anthracite is used as the top layer, the media

depth should be 30 in (76 cm) and the natural greensand (manganese zeolite) depth will be 24 in (61 cm). Greensand and anthracite media (or silica sand, if used) should have an effective size of 0.4 to 0.5 mm and a uniformity coefficient of 1.3 to 1.7.

- e. The filtration rate should not exceed 4 gpm/ft² (160 Lpm/m²) and a design rate of 3.0 gpm/ft² (120 Lpm/m²) is recommended.
- f. The gravel support media must be of sufficient depth and size to uniformly distribute the backwash water. The backwash rate should be within the range of 15 to 18 gpm/ft² (615 to 738 Lpm/m²). Some means for maintaining proper backwash rates should be provided. A backwash pump is recommended and selection of the proper pump capacity and head is necessary. Where distribution system pressure and flow are used, some reliable type of flow indicator should be provided.
- g. Sample taps should be provided prior to application of the permanganate, immediately ahead of filtration, and at the filter effluent. Also, sample taps should be provided between the anthracite (or other) medium and the manganese zeolite, and half-way down the zeolite.
- h. Process wastes must be handled and disposed as required by KDHE.

3. STABILIZATION BY SEQUESTRATION - Sequestering is a chemical treatment process used to keep iron and manganese in solution. Sequestration using polyphosphates and sodium silicate is generally suitable only for iron and manganese concentrations up to 1.0 and 2.0 mg/L, respectively,

- a. POLYPHOSPHATES - The polyphosphate should be applied before chlorine is added for disinfection and after any other treatment for iron and manganese removal. Mixing should be thorough and complete before chlorination. Satisfactory chlorine residuals shall be maintained in the distribution system. Polyphosphate shall not be applied directly into the well for groundwater supplies.

- 1) Phosphate chemicals must meet applicable AWWA Standards (4) and total phosphate applied shall not exceed 10 mg/L as PO₄.

- 2) Stock phosphate solution should be kept covered and disinfected by maintaining a free chlorine residual of about 10 mg/L.
 - 3) Polyphosphates shall not be applied ahead of iron and manganese removal treatment. The point of application shall be prior to any aeration, oxidation, or disinfection if no iron and manganese removal treatment is provided.
- b. SODIUM SILICATES - On-site pilot plant tests are required to determine the suitability of sodium silicate for the particular water and the minimum feed needed. Rapid oxidation of the metal ions such as by chlorine or chlorine dioxide must accompany or closely precede the sodium silicate addition. Injection of sodium silicate more than 15 sec after oxidation may cause detectable loss of chemical efficiency. Dilution of feed solutions below 5 percent silica as SiO_2 should also be avoided for the same reason.
- 1) Sodium silicate shall not be applied ahead of iron and manganese removal treatment.
 - 2) The amount of silicate added shall be limited to 20 mg/L as SiO_2 , but the amount of added and naturally occurring silicate shall not exceed 60 mg/L as SiO_2 .
 - 3) Liquid sodium silicate shall meet applicable AWWA Standards (4).
4. REMOVAL BY ZEOLITE ION EXCHANGE - Zeolite softeners should not be used for iron and manganese removal for water containing more than 0.3 mg/L of iron, manganese, or a combination of the two. Ion exchange is not acceptable where either the raw water or washwater contains dissolved oxygen.
5. REMOVAL BY LIME-SODA ASH SOFTENING - Iron and manganese in carbonate bearing water can be almost completely removed as carbonates at a pH of 8.0 and 8.5, respectively, by the addition of lime or soda ash. When this water is softened by the lime-soda ash process where the pH is about 11.0, the iron and manganese are removed as hydroxides.

6. TESTING EQUIPMENT - Testing equipment should be provided for all plants. The equipment should have the capacity to accurately measure the iron and manganese up to 2.0 mg/L. Using such equipment, the method detection limit for a particular analysis should be less than or equal to 0.1 and 0.05 mg/L for iron and manganese, respectively. Equipment capable of measuring higher iron concentrations should be available at those plants treating such waters. Where polyphosphate or sodium silicate sequestration is practiced, appropriate testing equipment should be provided.

P. AERATION AND AIR STRIPPING

Aeration involves the addition of air to water for the purpose of adding oxygen to the water. Air stripping involves the addition of air to water for the purpose of stripping volatile components such as dissolved gases and organics from the water. Groundwaters and hypolimnetic surface waters are usually impacted by these contaminants.

Dissolved gases include carbon dioxide which can affect softening requirements (see Section K on Softening or Hardness Removal), hydrogen sulfide which can cause T&O (see Section N on T&O Control), methane, and radon. VOC contaminants, like many T&O substances, are organic in nature (see Section Q on Adsorption with GAC); however, few T&O producing substances can be effectively removed by aeration.

Also, aeration can be used to provide oxygen for the purpose of oxidizing iron and manganese (see Section O on Iron and Manganese Removal) and to remove excessive amounts of chlorine dioxide used for disinfection. Air strippers may be used as preliminary treatment in the removal of carbon dioxide, hydrogen sulfide, iron, and manganese. Carbon dioxide levels greater than 10 mg/L are economically removed by air stripping.

Air stripping is useful for hydrogen sulfide removal when the concentration is on the order of 1 to 2 mg/L. Concurrent removal of carbon dioxide and hydrogen sulfide is not efficient unless preceded by stripping with air containing 10 percent carbon dioxide (e.g., flue gas) to remove the hydrogen sulfide followed by normal aeration to remove the carbon dioxide. Hydrogen sulfide should be removed prior to softening.

1. TYPES - Natural draft, forced or induced draft, packed towers, and pressure aeration are approved methods. Spray aerators are not recommended by KDHE.

2. PROTECTION OF AERATORS - All aerators except those discharging to lime softening or clarification plants shall be protected from contamination by birds, insects, wind-borne debris, rainfall, and water draining off the exterior of the aerator.
3. DISINFECTION - Aerators/air strippers shall be disinfected according to AWWA Standard C653 before being placed into service (4).
4. CORROSION CONTROL - The stability of the water after aeration should be determined and corrected by additional treatment, if necessary (see Section L on Stabilization).
5. AERATOR DESIGN CRITERIA
 - a. NATURAL DRAFT OR MULTI-TRAY AERATION AND FORCED OR INDUCED DRAFT AERATION - Induced draft aerators are preferred over natural draft aerators. Both types should provide that:
 - 1) Water is distributed uniformly over the top tray.
 - 2) Perforations in the distribution pan are 0.2 to 0.5 in (0.5 to 1.3 cm) in diameter, spaced 1 to 3 in (2.5 to 7.6 cm) on centers to maintain a 6 in (15.2 cm) water depth.
 - 3) Water is discharged through a series of trays. Natural draft aerators should have three or more trays separated by not less than 12 in (30 cm) between trays. Induced draft aerators should have five or more trays separated by not less than 6 in (15 cm) between trays.
 - 4) Inert media, such as coke, ceramic balls, or limestone that will not disintegrate due to freezing cycles, can be used in the trays with media depths ranging from 8 to 12 inches (20 to 30 cm). Synthetic media are preferred or trays without media can be used.
 - 5) The design loading rates are justified by the designer.
 - 6) Trays be slotted, heavy wire (0.5 in or 1.3 cm openings) mesh, or have perforated bottoms.

- 7) Construction be of durable materials resistant to the aggressiveness of the water and dissolved gases.
- 8) Loss of spray water from natural draft aerators by wind carriage be minimized using louvers sloped to the inside at an angle of approximately 45°.
- 9) Insects be controlled by a 24 mesh screen.
- 10) Sections of the aerator can be easily reached and removed for maintenance purposes.
- 11) The air is exhausted directly to the outside atmosphere.

In addition, forced or induced draft aerators should be designed to:

- 1) Insure that the water outlet is adequately sealed to prevent unwarranted loss of air.
- 2) Include a blower with a weather-protected motor in a tight housing and screened enclosure.
- 3) Insure adequate counter-current flow of air through the enclosed aerator column.
- 4) Include a down-turned and 24 mesh screened air inlet and a 4 mesh screened outlet.

b. PRESSURE AERATION - Pressure aeration involves the aeration of water under pressure and it may be used for oxidation purposes only if a pilot plant study indicates the method is applicable. It is not acceptable for removal of dissolved gases. Filters following pressure aeration must have adequate exhaust devices for release of air. Pressure aeration devices shall be designed to:

- 1) Give thorough mixing of compressed air with the water being treated.
- 2) Provide screened and filtered air, free of obnoxious fumes, dust, dirt, and other contaminants. The compressor shall be an oil-less type.

- c. AIR STRIPPING - Air stripping is used to remove radon, some T&O substances, and VOCs. Air stripping systems include packed towers and tray systems. In the packed tower, contaminated water is pumped to the top of the tower and distributed over the cross-sectional area of the tower which is filled with a porous packing material. Air is introduced at the bottom of the tower and flows upward, counter to the downward water flow. The packing material serves to maximize the water surface area in the tower and exchange of VOCs from the water to the air occurs at the air/water interface.

In tray systems, contaminated water flows over a distribution weir and along baffled aeration trays. Clean air is blown up through small holes in the aeration tray, forming a froth of bubbles with a large mass transfer surface area, which enhances volatilization of the contaminants. In addition to the packed tower and tray systems, another system design utilizes hydraulic jetting action to shear the contaminated water into microscopic globules of liquid while contacting them with an aspirated air stream. In general, the applicability of air stripping varies directly with the Henry's Law coefficient of the contaminant to be removed; although other factors do affect their design.

The air stripper should be designed to remove the target contaminant(s) from the water to a concentration significantly below the respective MCL(s) and, preferably, to a level that cannot be detected utilizing required analytical methods and instrumentation. The designer must also be concerned with avoiding excessive pressure drop in the air flow, e.g., "flooded" conditions where the pressure drop is so excessive that air can no longer flow through the stripper.

Though the mass transfer theory underlying packed towers has been well developed with various computer models widely available for the initial design, the tray systems and other innovative stripper systems have not been as extensively evaluated in the literature as the packed tower. For these systems, the initial design should be based on manufacturers' recommendations and confirmed through actual performance data from similar installations. KDHE recommends that small-scale pilot studies be conducted to confirm

the initial design and determine the mass transfer coefficients for removal of the specific contaminants from the actual water to be treated.

After the air stripper is in service, regular monitoring for the target contaminant(s) in the influent and effluent of the stripper will be required.

Additional design considerations for air strippers include:

- 1) Providing materials for air stripper walls, tanks, compartments, packing, and piping which are acceptable for use in contact with potable water.
- 2) Providing a moisture barrier (or demister) for packed tower systems.
- 3) Assessing whether pretreatment is necessary such as filtration for solids removal.
- 4) Metering the air and water flow to the air stripper and designating the flow pattern as countercurrent, concurrent, or cross-current.
- 5) Providing appropriate monitoring devices (with alarms and, if needed, telemetry) to detect fouling, flooding, overflow, significant pressure fluctuations, and other operating conditions that could adversely impact contaminant removal.
- 6) Providing influent and effluent sampling taps.
- 7) Designing the air stripper to reduce the contaminants of concern below the respective MCLs for all water temperatures and during all affected seasons.
- 8) Complying with all applicable air quality standards including permit requirements prior to any air discharge from the stripper system.
- 9) Making provisions for easy access into the air stripper to allow inspection, media replacement, maintenance and cleaning of packing materials or trays. If the removal of trays or other heavy parts will be necessary for maintenance, consideration should be given

to installing a crane in the air stripper building. Iron and manganese precipitation, carbonate deposition, and biological fouling are potential problems. Plugging or fouling of the air stripper due to precipitate deposits or solids buildup on the packing or trays may decrease the air flow rate through the system such that contaminant removal is adversely impacted. Posttreatment filtration for removal of precipitated solids may be necessary for some installations.

- 10) Maintaining chemical stability of the finished water.
 - 11) Providing an acceptable water supply during periods of O&M interruptions.
- d. OTHER METHODS OF AERATION - Other methods of aeration may be used if applicable to the treatment needs. Such methods include but are not restricted to diffusion aerators, cascade aerators, and mechanical aerators. The treatment processes must be designed to meet the particular needs of the water to be treated and are subject to the approval of KDHE.

Q. ADSORPTION WITH GAC

Activated carbon is available as PAC or GAC. PAC usage is generally limited to T&O control (see Section N) or seasonal control of pesticides, and GAC is used in filter-adsorbers (see Section J on Filtration) for T&O control but mainly in adsorbers for the removal of trace organics. GAC can be used to remove chlorine and certain inorganics such as radon and mercury but these applications are limited. This section deals only with GAC use in adsorbers for removal of trace organics.

1. DESIGN BASIS - Predictive tools such as diffusion or mass transfer models, laboratory small column tests, and isotherm measurements can provide a basis for the preliminary design. Isotherm constants for numerous toxic organics have been published but care must be exercised in their use (26). Depending on the complexity of a proposed installation, pilot plant studies may be required. Pilot plant studies can be valuable indicators of performance at full scale using preselected contactor conditions determined with small columns. Also, pilot studies can provide a data set for the

calibration of other predictive tools such as various models. The design engineer should submit to KDHE a detailed proposal for a laboratory, modeling, and/or pilot plant study appropriate for a particular project and seek KDHE approval prior to conducting the tests.

Major process design considerations for a GAC adsorber include the following:

- a) Design flow rate;
- b) Nature and concentration of the organic compounds in the untreated water;
- c) MCLs or other regulatory limits on the organic contaminants of concern;
- d) Type, size, and adsorptive characteristics of the GAC to be utilized in the adsorber;
- e) Type, dimensions, and configuration of adsorbers, i.e., the number, sequence, and arrangement of the separate GAC contactors;
- f) Location of the adsorber(s) in the water treatment process;
- g) Superficial (approach) velocity;
- h) Minimum empty bed contact time required for removal of contaminants to regulatory limit;
- i) Bed depth of GAC in adsorber(s); and
- j) Service time of adsorber(s).

2. CONTACTOR TYPE AND NUMBER - GAC adsorbers use various flow configurations of upflow with packed or expanded beds or downflow. Downflow contactors are recommended for water treatment applications. GAC adsorbers can be operated under pressure or with gravity, the latter being the most common arrangement. Multiple stage contactors are preferred for all PWSSs. Multiple units can be operated in series or parallel. Series or parallel piping configurations are preferred to minimize the effect of breakthrough without reliance on continuous monitoring. Where only two units are provided, each shall be capable of meeting the maximum daily demand. Where more than two units

are provided, the contactors shall be capable of meeting the design capacity with one or more units removed from service.

3. MEDIA REQUIREMENTS

- a) The carbon media must meet all applicable AWWA Standards (4). Virgin carbon is preferred because of possible contamination of regenerated carbon.
- b) Carbon media selection is based on head loss, backwash characteristics, hardness, rate of adsorption, and cost. Both 8 x 30 and 12 x 40 mesh size carbons have been used by utilities. The head loss is less in the larger 8 x 30 mesh carbon but the rate of adsorption is slower as compared to the smaller 12 x 40 mesh carbon.

4. MATERIALS OF CONSTRUCTION - Since GAC is corrosive when wet, special attention must be given to the adsorber construction. The columns should be constructed of non-corrosive material such as fiber glass or lined mild steel. The lining materials must be approved for use in potable water applications and be resistant to the abrasive action of carbon particles.

5. COMPETITIVE ADSORPTION - The organic analysis of the water should extend beyond the regulated organic compounds since naturally occurring, non-regulated organic compounds may have an impact on the design and operation of the adsorber. Competitive adsorption by natural organic matter may decrease the adsorption rate of the regulated organic compounds and increase the quantity of GAC required for removal of the regulated contaminants to their respective MCLs.

6. WATER STABILITY - The stability of both the treated and untreated water must be ascertained. A depositing water may rapidly clog the pores of the GAC while an aggressive water could descale valves, piping, media, etc. and increase the rate of corrosion.

7. DISINFECTION AND BIOLOGICAL ACTIVITY - Disinfectants do not prevent biological growth from occurring on the GAC because of their reaction with the GAC. Further, GAC has the capacity to dechlorinate

a water. Disinfection should follow the GAC adsorbers. Disinfection requirements for startup of contactors (and filter-adsorbers) are given in Section J on Filtration. Biologically active GAC has improved trace organic removal in adsorbers but such activity must be controlled to avoid undesirable effects.

8. BACKWASHING - Provisions for backwashing must be provided unless the adsorber does not function as a filter and is designed as a replaceable unit. If the source of water for backwashing the adsorber is the public water supply, proper cross-connection protection must be provided.

A backwash system should be designed to accomplish the following:

- a) Expand the carbon bed for cleaning but avoid excessive carbon loss or structural damage to the interior of the vessel.
- b) Settle the carbon bed in a stratified state so that the adsorptive wave front will be maintained and the carbon usage optimized.

Disposal of backwash water must be in a manner approved by KDHE.

9. REGENERATION OF SPENT GAC - On-site thermal regeneration is usually limited to larger PWSSs. Intermediate-sized plants may use off-site regeneration facilities but these and their transportation units must not use carbon which has been put to any other use. Small plants normally replace their spent carbon.

R. REMOVAL OF TRACE INORGANIC CONTAMINANTS

For inorganic contaminants not adequately removed by conventional treatment, additional treatment sufficient to meet applicable MCLs, SMCLs, or BATs is required. General information on processes to remove these contaminants is available (7,8). Ion exchange and activated alumina are potentially effective treatment processes for non-conventional inorganic contaminants. Pilot or in-plant studies must be conducted to develop specific design criteria for these processes.

S. MEMBRANE SEPARATION PROCESSES

A membrane in a membrane process is a barrier that affects the rate of passage of certain species through it: separation of the species from the feedwater is accomplished. Membrane processes which have been utilized in treatment of drinking water include reverse osmosis, nanofiltration, electrodialysis and electrodialysis reversal. Emerging membrane processes with application to drinking water include ultrafiltration and microfiltration.

Membrane processes differ in the types of membranes, the driving forces, the class of species separated from the feedwater, and the operating conditions required to effectively accomplish the separations. Depending on the specific properties of the membrane, differing resistances are created to the passage of dissimilar species present in the feedwater. Membrane processes can be categorized in terms of their pore size, molecular weight cutoff, or the pressure at which they operate.

In addition to desalinization of seawater and brackish water, low pressure reverse osmosis membranes have been employed for removal of some organic materials. Reverse osmosis is listed as a BAT for 11 inorganic compounds regulated in 40 CFR §141.62(B) as well as four radionuclides. Nanofiltration membranes, commonly referred to as softening membranes, were developed specifically for removal of divalent cations and dissolved organic materials from nonbrackish waters. Ultrafiltration and microfiltration potential applications include the removal of particles, cysts, bacteria, and colloids from feed streams.

A membrane treatment system will be approved by KDHE upon demonstration of feasibility by the design engineer and the submission of an acceptable plan for disposal of all wastes generated by the membrane process.

1. MEMBRANE TYPES - Membranes are available in different materials with varying chemical resistance and tolerance for biological and chemical conditions. Most commercial membranes are one of three types: cellulose acetate and its derivatives, polyamide, and thin-film composites. Typical membrane configurations for treatment of drinking water include spiral wound, and small-diameter hollow fiber. Operational conditions and useful life vary depending on the type of membrane selected.

2. USEFUL LIFE OF MEMBRANES - The membrane, itself, typically represents a major cost component in the overall water system. Membrane replacement must be considered in assessing the overall cost of operating the treatment facility. Factors to consider include estimated membrane life and supplier's performance guarantees.
3. PERFORMANCE EVALUATION OF MEMBRANES - Membranes should be fully evaluated for a proposed installation. Recommended testing parameters for membrane comparisons include the following:
 - 1) Composition of the feedwater, including concentrations for substances above and below the rejection range of the membrane;
 - 2) Composition of the concentrate, with concentrations of the same substances analyzed in the feedwater;
 - 3) Number of elements in the membrane module;
 - 4) Feed flow rate;
 - 5) Applied pressure;
 - 6) Operating temperature;
 - 7) Operating pH;
 - 8) Recirculation rate for cross-flow microfiltration, ultrafiltration, nanofiltration, and reverse osmosis;
 - 9) Pressure drop across the system; and
 - 10) Percent recovery.

Prior to initiating the design of a membrane treatment facility, KDHE should be contacted to determine if a pilot plant study will be required. In most cases, a pilot plant study will be required to determine the best membrane to use, the type of pretreatment, type of post treatment, the bypass ratio, the amount of wastes generated, process efficiency, and other design criteria.

4. PRETREATMENT REQUIREMENTS - Membrane performance and life expectancy depend heavily on the quality of the feedwater. Acceptable feedwater characteristics are dependent on the type of membrane and operational parameters of the system. Accurate water analyses must be completed on the source water for all relevant test parameters such as organic and mineral content as well as biological activity in order to adequately assess pretreatment requirements. Pretreatment may be needed for turbidity reduction, iron or manganese removal, stabilization of the water to prevent scale formation, microbial control, chlorine removal, dissolved solids or hardness reduction, and pH adjustment.
5. BYPASS WATER - The design of the membrane treatment system may include a bypass of a portion of the raw water around the membrane unit provided the treatment objectives and regulatory limits are met. Such a bypass may be necessary with reverse osmosis installations in order to obtain a stabilized water where the permeate through the membrane is virtually demineralized. However, a bypass would not be appropriate where the membrane system is utilized for compliance with the SWTR pathogen removal requirements.
6. SYSTEM REDUNDANCY - Membranes should be arranged within groups constituting separate blocks or treatment trains. Sufficient blocks should be provided so that one may be taken out of service for cleaning, repair, or modification while still meeting finished water demand requirements.
7. CLEANING THE MEMBRANE - Membrane cleaning procedures are membrane and foulant specific. The manufacturer's recommendations as to cleaning solutions and procedures should ordinarily be followed. Care must be taken in the cleaning process to prevent contamination of both the raw and finished water system. It is recommended that a non-destructive method of assessing the membrane condition be provided including the determination of the type of foulant present.
8. POST TREATMENT REQUIREMENTS - Additional treatment may be required for the product stream. Post treatment can include degasification for carbon dioxide and hydrogen sulfide removal, pH adjustment for stabilization, and chlorination for bacterial control.

9. INSTRUMENTATION - A minimum level of instrumentation is required to ensure fail-safe operation and to avoid potential damage to the membrane. Such instrumentation should include system shutdown, alarms, or other indicators where changes in operating conditions including feedwater quality could potentially impair membrane performance, such as inadequate feedwater pressure, improper feedwater flow rate, excessive feedwater turbidity.
10. WASTE DISPOSAL - Wastes generated by different parts of a general membrane process include pretreatment waste, membrane concentrate, cleaning waste, and posttreatment waste. The system design must provide for management of all such wastes in compliance with KDHE regulations. Each waste stream must be fully characterized through appropriate analyses or modeling and alternate disposal options fully evaluated. Potential disposal options include land application, surface water discharge, injection wells, and discharge to a wastewater treatment plant.
11. OPERATOR TRAINING AND STARTUP - The ability to obtain qualified operators must be evaluated in selection of the treatment process. The necessary operator training shall be provided prior to plant startup.

T. FLUORIDATION

Commercial sodium fluoride, sodium silicofluoride, and hydrofluosilicic acid should conform to applicable AWWA Standards (4) for these materials. Other fluoride compounds which may be available must be approved by KDHE.

1. REQUIREMENTS - KDHE will approve the fluoridation of a PWSS under the following conditions:
 - a. An application has been submitted to KDHE for permission to fluoridate the water supply by the PWSS.
 - b. Plans and specifications covering the following items have been submitted to and approved by KDHE:
 - 1) Chemical to be used as a source of fluoride.
 - 2) Methods of storing and handling the chemical.
 - 3) Feeding equipment.

- 4) Point of application.
 - 5) Rate of flow at point of application and flow characteristics.
 - 6) Automatic controls.
 - 7) Safety precautions.
 - 8) Laboratory controls and equipment to be used for determination of dosage and fluoride content of water.
- c. A copy of the city ordinance or equivalent document of a water district board authorizing fluoridation of the water supply must be submitted to KDHE.
2. APPLICATION PRINCIPLES AND CRITERIA - The following general principles will be used in promotion and administration of the program by KDHE.
- a. No fluoridation project should be undertaken without the full cooperation and approval of the city administration, the water department, and the local health department, as well as KDHE.
 - b. In considering an application for approval of fluoridation, KDHE will consider the qualifications of water works operators to perform the control and maintenance operations required.
 - c. Available chemicals and recommended methods of feeding are listed in Table 4.

TABLE 4

FLUORIDATION FEED CHARACTERISTICS

Name	Form	Feeder	Remarks
Sodium Fluoride	Powder	Saturator	
Sodium Silicofluoride	Powder	Dry	Solubility Low
Hydrofluorsilicic Acid	Liquid*	Solution	Corrosive

*Recommended for most PWSSs.

- d. Fluoride chemicals should be isolated from other chemicals to prevent accidental contamination. Compounds shall be stored in covered or unopened shipping containers and should be stored inside a building. Unsealed storage units for hydrofluosilicic acid should be vented to the atmosphere at a point outside the building. Bags, fiber drums, and steel drums should be stored on pallets.
- e. When other chemicals are being fed, chemical compatibility must be considered. Fluoride compounds shall not be added before or with lime-soda or ion exchange softening. Whenever possible, fluoride should be added after filtration. In surface water plants, the ideal location for fluoride addition is in the line from the filters to the clearwell. For groundwater, addition should be at the point of entry to the distribution system.
- f. Water used for sodium fluoride dissolution shall be softened if its hardness exceeds 75 mg/L as calcium carbonate.
- g. Scales, loss-of-weight recorders or liquid level indicators, as appropriate, shall be accurate to within 5 percent of the average daily change in reading for the chemical feeders.
- h. Feeding equipment must be accurate within 5 percent, and facilities must be provided for accurately weighing the amount of chemical used. Solution feeders must be of the positive displacement type with a stroke rate of not less than 20 strokes per minute and must be provided with an accurate means for measuring the water used in making up the solution, except where hydrofluosilicic acid is fed directly. The point of application of the hydrofluosilicic acid, if into a horizontal pipe, shall be in the lower half of the pipe.

The maximum design operating pressure of the feed pump should be at least one-third more than the expected operating pressure at the injection point.

Selection of the solution feed capacity so that the discharge rate is in the lower half of the operating range is important. If the pump operates at either extreme of the operating range the operator will have difficulty in matching flow changes.

- i. Fluoride solutions shall not be injected to a point of negative pressure.
- j. The electrical outlet used for the fluoride feed pump should have a nonstandard receptacle and shall be interconnected with the well or service pump.
- k. Anti-siphon devices shall be provided for all fluoride feed and dilution water lines. The dilution water pipe shall terminate at least two pipe diameters above the solution tank.
- l. Saturators should be of the upflow type and be provided with a meter and backflow protection on the makeup water line.
- m. A meter with a contactor is required to assure addition of fluoride in proportion to the flow.
- n. Entrained air tends to come out of solution forming bubbles in the feed lines. The air bubbles can interfere with the feed and should be bled from the lines whenever they appear.
- o. Secondary control systems for fluoride chemical feed devices may be required by the reviewing authority as a means of reducing the possibility for overfeed. These may include flow, pressure switches, or other devices.
- p. Special precautions must be taken to protect operators against possible injury from concentrated chemicals. A dust mask, rubber apron, and rubber gloves are needed, and if hydrofluosilicic acid is used goggles are also needed. Acid systems should also have flushing water at the place where carboys are handled. Operators must be fully instructed in the proper handling of fluoride chemicals. An eye washer and an emergency shower should be provided.
- q. Provisions must be made for the transfer of dry fluoride compounds from shipping containers to storage bins or hoppers in such a way as to minimize the quantity of fluoride dust which may enter the room in which the equipment is installed. The enclosure shall be provided with an exhaust fan and dust filter which places the hopper under a negative pressure. Air exhausted from fluoride handling equipment shall discharge through a dust filter to the outside of the building.

Provisions shall be made for disposing of empty bags, drums, or barrels in a manner which will minimize exposure to fluoride dusts. The best practice is to rinse all empty containers with water.

- r. Suitable laboratory space and equipment must be provided for the determination of the fluoride content of the water in accordance with Standard Methods (10). The spectrophotometer is the best all around equipment for running fluoride tests. Testing laboratories and larger water plants use the electrode method mainly because of the ease of running a large number of samples and the greater tolerance of interferences.

The approved methods are SPADNS and the ion selective electrode methods (10). Operators responsible for control of fluoridation must demonstrate their ability to perform such tests to KDHE prior to beginning fluoridation of their water supply.

Immediately after commencing fluoridation, samples from the plant tap and the distribution system must be submitted to KDHE together with the report of fluoride determinations made on duplicate samples. This procedure will be followed until KDHE is satisfied with the uniformity of the results.

Thereafter, fluoride determinations will be made on regular samples submitted to the laboratory for bacteriological analysis, and routine tests run at the plant in accordance with the following schedule:

plant tap	1 per day
distribution system	4 per week

- s. Daily records should be kept of the amount of chemicals fed, water pumped, and fluoride determinations. Quarterly reports of fluoride analyses must be submitted to the Bureau of Water, Division of Environment, Kansas Department of Health and Environment, Topeka, Kansas 66620.
- t. No fluoridation equipment shall be placed in operation until the installation has been inspected by a representative of KDHE and found to be in conformance with the plans and specifications approved by KDHE.

